On the relation between ENSO and changes on coastal vegetation– does coastal vegetation follow El Nino events?

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by

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Abstract

Coastal vegetation has been suffering a considerable retreat both on biodiversity and extension, on the last decades. Mangroves are an example of such ecosystems suffering greatest losses due mostly to anthropogenic pressure, in the past.

Concerns have been raised about the impact of climate change on such biological and ecological complex systems due to their particular and sensitive location within and along land-ocean boundary. Northern Australian mangroves are barely influenced by human pressure; therefore, it makes them a suitable site to assess the importance of possible changes caused by various natural threats.

It is known that Northern Australian territory is intensely affected by ENSO, experiencing long and severe drought periods. Despite the obvious relationship between mangroves ecosystems and rainfall, as well as the strong association between rainfall and ENSO, according to our current knowledge it has not been yet established a direct association between mangroves and ENSO. The aim of this study therefore is to establish the correlation between NDVI (normalized difference vegetation index) and ENSO, and to further assess its strength using rainfall as a medium and a directly correlation, both using NDVI from NOAA AVHRR 8 km resolution. Concrete long term effects of ENSO variability arise, for instance, due to its long temporal coverage. The results show that SOI is the best ENSO proxy for establishing such an association. Moreover, it is proved that NDVI response to rainfall is almost non-existent on coastal areas during the wet season where ENSO occurs, possibly due to the known resilience of mangrove ecosystems to high-salinity environments. To conclude it was proved here the existence of a weak association between mangroves NDVI and ENSO on Northern Australia. Although, such results are not satisfactory and robust, thus demanding the use of a fine-scale resolution products to untangle such association. Finally the rainfall reveal itself on this study insufficient to explain mangrove above-normal when it occurs less rainfall, leading this study to implementation of variables such as temperature.

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List of acronyms

AVHRR:	Advanced Very High Resolution Radiometer
DJF:	(December, January, February)
ENSO:	El Nino – Southern Oscillation
GPCC:	Global Precipitation Climatology Centre
IOD:	Indian Ocean Dipole
JJA:	(June, July, August)
MAM:	(March, April, May)
NAO:	North Atlantic Oscillation
NDVI:	Normalized Difference Vegetation Index
NDVIa:	Normalized Difference Vegetation Index Anomaly
NIR:	Near-infra Red band
NOAA:	National Oceanic and Atmospheric Administration
Ra:	Rainfall Anomaly
RED:	Red band
SOIa:	Southern Oscillation Index Anomaly
SON:	(September, October, November)
SST:	Sea Surface Temperature
SSTa:	Sea Surface Temperature Anomaly

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1. Introduction

1.1 Background and Significance

The Earth’s climate is a highly complex and extremely dynamical system consisting of five major interacting components: the atmosphere, hydrosphere, cryosphere, land surface and the biosphere. The main external driving force, with power enough to trigger these components, is the Sun. It plays a key role in providing the necessary energy to induce the movement of air masses across the oceans thus, boosting several interactions inherent to all these components over the globe. However, there are other several external forcing factors, which can potentially change these systems, one of them is human pressure (Trenberth et al., 1996).

Till date most atmospheric models are hard pressed to predict the fluctuations occurring within the atmosphere accurately for more than a two-week period. Yet, it is possible monitoring the long-term variability of such weather events that are known to occur at the different time-and space-scales; this statistically significant effect on the climate variability is referred as climate change. The Earth’s climate variability results from the interdependence between the coupled atmosphere-ocean system, as well as its interaction with land features such as vegetation and albedo (Hegerl et al., 2007).

Climate variables such as temperature, precipitation, winds, etc., which are recorded on a daily, monthly or annual scale allow gathering useful information, for forecasting and modeling purposes, of largest scale atmospheric phenomenon. A well- known example of a global climate pattern which influence the regional climate variables mentioned above, is the El Nino/Southern Oscillation (ENSO), a coupled interaction between atmosphere-ocean (Trenberth, 1997).

El Nino (La Nina), as is commonly known, is associated to warmth (cooling) of the sea-surface temperatures over the tropical Pacific. This basin-wide phenomenon generates a reactive behavior of the atmosphere, represented by a drop on the surface pressure over the Pacific; this manifestation is called Southern Oscillation (Trenberth, 1997).

Due to extreme weather events and climate changes associated with the occurrence of ENSO, the underlying impacts and implications have been hardly studied on a regional level over the entire globe.

Therefore, it is important to understand that the inter-annual climate variability induced by ENSO it is not confined to the Pacific region exclusively, but for example, it is known to be teleconnected to anomalous rainfall patterns in the tropics and extra tropics regions (Ronghui and Yifang, 1989; Ropelewski and Halpert, 1986). ENSO being assigned as the most influent global climate patterns, a large number of studies have attempted to evaluate its strength and impact on other but less influent climatic patterns (NAO, IOD, etc.) around the world (Ashok et al., 2001; Brönnimann et al., 2007).

The strength of ENSO events is measured by what are known as ENSO proxies. The most common proxies are the well–known Southern Oscillation Index (SOI), an anomalous surface pressure difference between Tahiti and Darwin, followed by the Sea Surface Temperatures (SST). The latter ones are habitually assigned to "boxes" within specific latitudes over the entire Pacific Ocean region, also called NINO regions (Brönnimann et al., 2007; Trenberth, 1997). Despite some authors proved that SOI presents strongest associations with rainfall patterns, due to its large-scale pressure influencing directly the rainfall; others stated SSTa as better indicators of the rainfall variability associated to ENSO (Nicholls, 1989; Risbey et al., 2009)

Consequently, several studies were conducted over the years, around the World, to comprehend and analyze the influence of ENSO phase on rainfall variability (Chang et al., 2004; Giannini et al., 2000; McBride and Nicholls, 1983; Ropelewski and Halpert, 1987, 1996). For example, McBride and Nichols, in 1983, proved that there was a distinctive seasonal cycle in the association between rainfall and SOI in Australia, also finding that the strongest positive correlations were in eastern and northern of this territory. Likewise, Ropelewski and Halpert, in 1986, proved that indeed the dry conditions existent in Australia tend to be associated to ENSO.

Due to thunderstorms and convection processes over warm ocean waters, the changes in the patterns of sea surface temperatures are crucial for the distribution of the rainfall in the tropics. In other hand, it is known that the atmospheric circulation patterns which presents a faster response to changes in its equilibrium compared to the ocean, are not restricted to tropics only, instead it extends to mid and high-latitudes, (Ghil, 2002) .Often, due to the later response from the atmosphere to the changes occurring on the oceans, it had become a valuable practice the use of lagged correlations to assess the seasonal rainfall predictive power of SST's (McBride and Nicholls, 1983; Pernetta and Elder, 1992; Ropelewski and Halpert, 1987).Though, recent studies have proved that the use of simultaneous correlations between ENSO proxies and rainfall instead of lagged, would present stronger correlation coefficients (Risbey et al., 2009).

The majority of the studies, using SOI proxy, proved indeed that there is moderate to strong positive association between SOI and rainfall, on North Eastern Australia. Yet, other authors achieved similar results using SSTa proxy, though presenting a reverse on the direction of the association (negative), due to the complementary nature of this processes (Nicholls, 1989). Nicholls, in 1989, took into consideration the influence of SST over the Central Indian Ocean and its influence on rainfall variability over Australia. Later on, Saji *et al.,* in 1999, proved the existence of an Indian Ocean Dipole over a 40's years study period enhancing then as a relevant driver for rainfall variability on Australia corroborating with Nicholls findings in 1989 (Saji et al., 1999).

However, atmosphere's influence is not restricted to its straightforward dependence with oceans but also is, intrinsically related to the terrestrial biosphere. Though, due to the complexity and dynamic association of these two components, the nature of this association is still not yet fully understood. Hence, several efforts had been made to clarify it, mostly adapting General Circulation Models (GCM) to vegetation dynamics, originating then the known Dynamic Global Vegetation Models (DGVM) (Krinner et al., 2005).

An alternative is the use of a simplistic approach by merely assessing the photosynthetic activity of different terrestrial ecosystems and try to establish a link with different climate variables, as some authors proved both on a global and regional scale (Boschetti et al., 2013; Kawabata et al., 2001; Richard and Poccard, 1998; Schultz and Halpert, 1993). With the appearance of Advanced Very High Resolution Radiometer (AVHRR) from National Oceanic and Atmospheric Administration (NOAA), in 1983, it became possible monitoring the photosynthetic activity of all terrestrial ecosystems on a worldwide scale, periodically. One of the most used index to assess vegetation condition is the Normalized Difference Vegetation Index (NDVI) (Anyamba et al., 2002). The main advantage of this sensor is its high temporal resolution regardless its coarse spatial resolution (8 km). Nonetheless, it has been commonly used as proxy for the study of interannual climate variability in different regions, and particularly useful on regions where *in situ* measurements are scarce (Anyamba and Eastman, 1996).

Recently, it has been explored the vegetation-climate relationship through the use of links between NDVI and climatic variables such as rainfall. Some authors proved that indeed annually composites of NDVI follow annual rainfall means (Nicholson et al., 1990). Yet, NDVI is not directly affected by rainfall; instead it is responsive to soil moisture. Richard and Poccard, in 1998, proved successfully the use of previous multimonths sums of rainfall totals to assess the relationship comparatively to a reference monthly NDVI, in order to represent the vegetation later response to rainfall effectively (Nicholson et al., 1990; Richard and Poccard, 1998). Similar positive association between NDVI and rainfall was described for Australian Territory by Kawabata *et al.* in 2001 (Kawabata et al., 2001).

Despite the not clear association between NDVI and ENSO events, some recent efforts have been done to untangle such problem. Anyamba and Eastman, in 1996, proved using ENSO proxies the existence of a reliable link between ENSO anomalies over Pacific and East Africa (Anyamba and Eastman, 1996).
Consecutively it was established similar links for other regions. For an instance, Myeni *et al.* (1996) used another ENSO proxy, namely NINO3 region. He proved that large scale anomalies on sea surface temperatures over Pacific were associated to major negative anomalies on a drought period for Eastern and Central Australia (Myneni et al., 1996). Similarly approach, though using SOI, was used by Maisongrande *et al.* (2007) proving as well, a strong positive relationship between NDVI anomalies and ENSO for all Australia. Other example was Lu *et al.* (2012) findings, which revealed with success, different ENSO sensitive regions across different types of vegetation all over China (Lü et al., 2012).

1.1.1 Mangroves

Coastal wetland ecosystems are extremely valuable ecosystems that have been endangered by the well-known climate changes. Due to their particular location, coastal wetland ecosystems are areas of easy access that connect land to sea and have high productivity and extraordinary biodiversity. These characteristics are one of the many reasons of high human settlement rates in coastal zones, leading to a dramatic overexploitation of the valuable resources available in such areas (Nicholls et al., 2007).

Mangroves in general are known for being highly productive ecosystems. Yet, in the last decades, the critically endangered number of mangroves had suffered a significant, and concern increasing throughout the World (Kathiresan and Bingham, 2001a).

For the majority of authors, mangroves are agglomerates of tropical shrubs and trees belonging to different families with similar adaptive responses to high-salinity environments, tidal currents, high temperatures, anaerobic soils and strong winds that grow on tropical and subtropical areas (see e.g. (Blasco et al., 1996; Kathiresan and Bingham, 2001b; Schaeffer-Novelli et al., 2000).

Commonly, mangroves are globally distributed within 30°N and 30°S from Equator, in the tropical and sub-tropical regions, distributed around one hundred twenty-four countries. Blasco et al. (1996) alleged that mangroves distribution was constrained to areas where the water temperatures of the warmest month exceed 24°C; in the case of waters not exceed the 24°C during the year they would be absent (Blasco et al., 1996).

Therefore, following Duke (1998), Blasco (1984) and Spalding et al. (1997) statements, the overall global distribution patterns of mangroves are mainly set up by temperature limitations, both air and sea surface temperatures, restraining mangroves mostly to tropical regions. The response of each mangrove species to low air temperatures delimits their occurrence. In 1984, Blasco presented a four mangroves distribution division according with the influence of both, precipitation and temperature. Australian mangroves species covered three of those group classification: warm humid areas, sub-humid areas and semi-arid areas where mangroves are rarely found. Such classification enhanced the importance of climatic conditions for the particular mangroves species habitat suitability (Blasco, 1984; Duke et al., 1998; Spalding et al., 1997).

In the last three decades, much effort has been placed in the study of mangroves, starting for example with the famous works of FAO (2007), IUCN (2006), Lugo and Snedaker (1974), Blasco *et al.* (1996), Field (1995), Tomlinson (1986), Duke *et al.* (1998) and Smithsonian Institute(1996), Kathiresan and Binghman (2001), and many others. Their analyses provide powerful applications to the study of this particular ecosystem. Those include the preservation of shorelines that contribute to soil formation. Furthermore, as a source of valuable coastal food chains and for providing the ideal conditions for an extensive list of mammals, birds, insects as well as algae, fungi, etc. Their role as filters, separating sediments from nutrients, for upland runoff, it is also one of the assets why are important and for being also a source of valuable fuelwood (Blasco et al., 1996;

Duke et al., 1998; FAO, 2007; Field, 1995; Institution, 1996; Kathiresan and Bingham, 2001b; Lugo and Snedaker, 1974; McLeod and Salm, 2006; Tomlinson, 1986).
Field, in 1995, alerted for the concern of climate change impacts on mangrove ecosystems. Along with sea level and temperature rise, Field enhanced the importance of changes on rainfall distribution as well as higher storms frequency events; factors that need to be considered as directly stressors on mangroves growth (Field, 1995).
Mangrove species diversity is known to increase with higher coastal rainfall and fresh water availability. For example in Australia the number of species is quite inferior in the west coast, which experiences a dry climate compared to east coast where around 20 species are established due to highest amount of rainfall (Duke et al., 1998). Therefore it is expected that mangroves, which face a decrease on rainfall, experiencing simultaneously an increase of evaporation and further on, an increasing of salinity, thus will present diminish on its growth, and consequently a retreat on mangrove cover area and species diversity (Duke et al., 1998; Gilman et al., 2008). The figure 1 presents the distribution of species in Australian Continent according with the different rainfall regimes all over the continent.

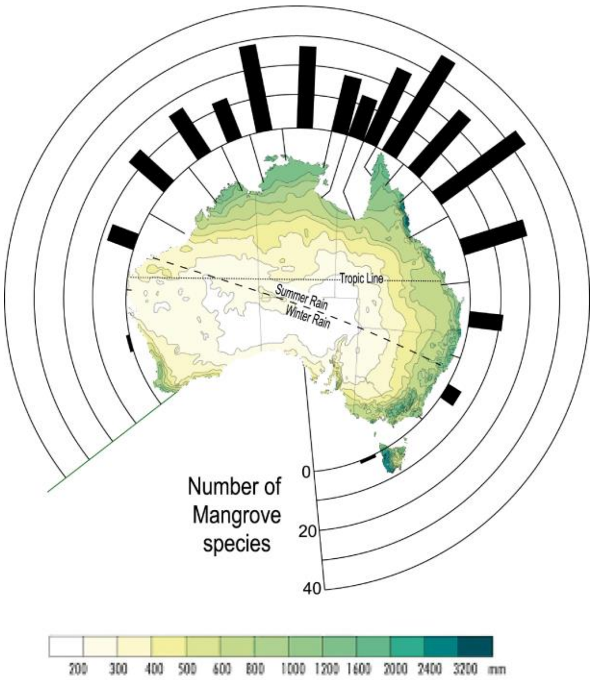

Figure 1- Histogram bars of species numbers by sub region affected by gradients in coastal mean annual rainfall. Shaded zones show levels of annual rainfall in mm (Duke, 2006)

Australia is known for its rich biodiversity, which is in fact a consequence of the broad range of environmental conditions which occur all over the country. Also for being a country with an extensive area, though a lower population density, its ecosystems are not under as an intense pressure as similar ecosystems in other parts of the world, thus presenting better conservancy and protection legislation (Committee, 2006; Common and Norton, 1992).

1.2 Research Problem

Commonly, mangrove ecosystems are known by their complexity and important role on coastal areas. One of the main concerns related to this ecosystems it is their response to climate change (Gilman et al., 2008). According with some authors, one of the major threats for this ecosystem, especially its growth and spatial distribution, is a redistribution of rainfall patterns around tropics and sub-tropics regions (Duke et al., 1998; Field, 1995; Gilman et al., 2008). It is known that such redistribution is in large part associated to global climate patterns, such as ENSO (Ropelewski and Halpert, 1987).
Several studies had established successfully a relationship between rainfall and NDVI, the latter commonly used as a proxy for vegetation growth or as its common know the Earth's greenness (Boschetti et al., 2013; Nicholson et al., 1990). The assumption that NDVI changes may be forced by ENSO started being explored recently (Anyamba and Eastman, 1996; Maisongrande et al., 2007; Mennis, 2001; Myneni et al., 1996). Meanwhile, similar studies were done assessing the impact of rainfall, which is known for its direct role on ecosystems functioning, on vegetation growth patterns through the use of NDVI (Lugo and Snedaker, 1974; Richard and Poccard, 1998). Moreover, mangroves are known to be, at a regional scale, highly influenced by tidal ranges, rainfall, waves and rivers and in a global scale by temperature (Alongi, 2002). Due to the dynamic and unique characteristics of mangrove ecosystems it is expected that quick changes on climate events may induce significant and immediate changes on mangroves (Blasco et al., 1996). Sharing the same concern that Field (1995) and Gilman *et al.* (1998) about mangroves ecosystems response to possible changes on climate patterns, and knowing that such changes are linked to disturbances on precipitation patterns which in turn is known to strongly impact the mangrove growth (Duke et al., 1998; Field, 1995; Gilman et al., 2008). This study will try to evaluate if there and how strong is, the relationship between mangrove vigor, using NDVI, and ENSO patterns for a period of 24 years (1982-2006). The latter due to the largest temporal

resolution availability of NDVI dataset (AVHHR), allowing to observe interdecadal role of ENSO on Northern Australia mangroves.

1.3 Research Objectives

Overall Objective

Characterize the relationship between changes on mangrove greenness and ENSO influence.

Specific Objectives

- Quantify the impact of ENSO on rainfall variability, in Northern Australia.
- Assess the effect of ENSO on mangroves greenness.
- Assess the strength of rainfall, as a stressor, on mangroves greenness.

1.4 Research Questions

Overall Research Question

Does mangrove greenness in Northern of Australian Territory, follows El Nino occurrence?

Specific Research Questions

1) Is there a relationship between ENSO phenomenon and rainfall variability, and what is its spatial variability across the Northern Australian Territory?

2) Is there an association between mangrove greenness and rainfall variability over the Northern Australia?

3) Is there a relationship between mangrove greenness and ENSO proxies?

4) Does the mangrove greenness differ between coastal areas (not) affected by ENSO?

1.5 Assumptions

This research is based on the following assumptions. First, the use of NDVI here is meant to express vegetation vigor, more specifically mangrove vigor. This index is commonly used for several other authors with the same purpose (Anyamba et al., 2002; Richard and Poccard, 1998).
Additionally it was assumed a non-significant impact of human pressure over the entire study area. Northern Australia is known for not being densely populated and strong and effective policies with respect to mangroves conservation (FAO, 2007; MangroveWatch, 2013). Additionally it was not assumed on this study the direct influence and the main role of temperature on mangroves distribution and growth according with Duke *et al.* (1998) and Blasco (1984) (Blasco, 1984; Duke et al., 1998).

1.6 Hypothesis

Hypothesis 1:

The null hypothesis for research is that:
H0: There is no relationship between ENSO phenomenon and rainfall variability of Northern Australia.

$$H0: r_s = 0$$

Ha: There is a negative relationship between ENSO phenomenon and rainfall variability of Northern Australia.

$$Ha: r_s < 0$$

Where r_s, is the Spearman's correlation coefficient.

Hypothesis 2:

The null hypothesis for research is that:
H0: There is no relationship between mangrove greenness and rainfall variability on the Northern Australia.

$$H0: r_s = 0$$

Ha: There is a significant positive relationship between mangroves greenness and rainfall variability following areas (non-)affected by ENSO.

$$Ha: r_s > 0$$

Where r_s, is the Spearman's correlation coefficient.

Hypothesis 3:

The null hypothesis for research is that:

H0: There is no relationship between ENSO phenomenon and mangroves greenness uniformly, across all Northern Australia.

$$H0: r_s = 0$$

Ha: There is a positive relationship between ENSO phenomenon and mangrove greenness uniformly across all Northern Australia.

$$Ha: r_s > 0$$

Where r_s, is the Spearman's correlation coefficient.

Hypothesis 4:

The null hypothesis for research is that:

H0: Mangrove greenness is not significantly different between coastal zones varying in ENSO teleconnection.

$$H0: U_1(x) - U_2(x) = 0$$

Ha: Mangrove greenness is significantly higher in coastal zones varying in ENSO teleconnection.

$$H0: U_1(x) - U_2(x) > 0$$

Where U_1 is the mean greenness of mangroves occurring in coastal zones significantly influenced by ENSO and U_2 is representative of the mean greenness of mangroves on the coastal zones that are not significantly influenced by ENSO.

1.7 Research Problem - Conceptual Framework

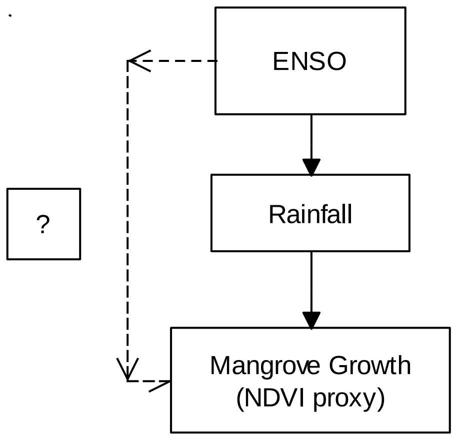

Figure 2- Research problem schematic representation

2. Materials and Methodology

2.1 Spearman's Correlation

Correlation tests measure the strength of the association between two variables. There are two main different tests to assess the strength of a relationship, being the Pearson's Product moment the most common correlation test, with the particularity that relies on the assumption that our variables should present a Gaussian distribution. A less robust alternative though less sensitive to outliers, which is one of the main advantages, is the Spearman's rank correlation (r_s) (Quinn and Keough, 2002).

The Spearman's rank correlation as it is implicit on the name uses the rank of the variables instead of the variables *per se* to measure the association between two variables. It is the non-parametric alternative test to Pearson's correlation. To be able to correctly use the Spearman's Rank correlation the two variables should present a monotonic relationship within their ranks. By monotonic is understood that, when one variable increases the other decreases or both increase/decrease simultaneously.

The following table (Table 1) was produced by Zar (1972), illustrating the critical values of the Spearman Rank's Correlation for one tailed test, with a certain degree of freedom (Zar, 1972).

Zar (1972) assumed that only for a sample larger than 100 it would be necessary the use of a Student's test, therefore demanding the use of n-2 degrees of freedom. So in this work the chosen degrees of freedom are equal to the number of cases ($n=24$) (Zar, 1972).

Table 1- Critical Values for Spearman's Rank Correlation for One-tailed test. (Adapted from (Zar, 1972))

	Critical Values (One tailed)		
Degrees of freedom	**0.10**	**0.05**	**0.025**
22	**0.284**	**0.361**	**0.425**
23	**0.278**	**0.353**	**0.415**
24	**0.271**	**0.344**	**0.406**

It is important refer that correlation do not assume causality. The r_s values are within -1 and 1. A coefficient of -1 indicates a robust negative association meaning that when one variable increases the other decreases. In other hand, a coefficient of 1, reflects a robust positive correlation, with two possible meanings, or the variables either decrease or increase.

2.2 Mann-Whitney test

One of the most robust rank-based non-parametric tests is the Mann-Whitney test.
It is commonly used for two samples, and it allows evaluating if whether this two independent samples have the same population mean or median (Agresti and Franklin, 2007).
Meanwhile, there are necessary basic assumptions, which need to be fulfilled in order to execute this test. One of those assumptions requires that each group is characterized by being an independent random sample; other is the non-assumption of a normal population distribution. The latter one is the principal advantage of such a test, meaning that, that a non-parametric test handle possible outliers more successfully than a parametric one (Quinn and Keough, 2002).
Despite the non-assumption of an underlying normal distribution, the non-parametric test assumes the equality of variances within the two different populations; otherwise, its performance is not meaningful.

Therefore, the null hypothesis for a Mann-Whitney test used on this study is based if there are not statistically differences between, mangrove mean abundance on an ENSO area and Non-ENSO area, where the difference between two samples is represented by Δ.

$$H0: \Delta=0$$

And the alternative hypothesis,

$$H1: \Delta\neq0$$

Though, it is possible to test the alternative hypothesis as one sided significance level, which was the case on this study.

The procedure for this test is initially ordering the data, label it according with group, and then proceed to the attribution of rankings, independently of the group they are inserted; on this ranking operation, tied values get the average of their correspondent rankings.

The following step is the sum of sample ranks for each group, being R_1 the sum of ranks of mangrove abundance on an ENSO area and R_2 the sum of ranks mangrove abundance on a Non-ENSO area. Then to calculate the Mann-Whitney test U it was applied the following formula (adapted from (Agresti and Franklin, 2007)), where n_1 is the number of subjects in the group.

$$U_1 = R_1 - (n_1 (n_1+1))/2 \qquad (2)$$

Similar procedure was used on R_2, and to be able to decide if whether it is possible to reject the null hypothesis it was calculated the difference between the U_1 and U_2. To conclude is possible extract d from a Mann- Whitney tables according with level of confidence defined (α=0.1). Theoretically, the formula (2) is one way of assessing the significance of the test. Then, in cases where U is bigger, it is possible to reject the null hypothesis.

$$U > n_1 - n_2 - 2d \qquad (3)$$

Once the two groups of this study have a huge population each, this test was executed under the premises assumed by the software SPSS 20, with same principles to those described here.
Therefore, if the p-value calculated on SPSS is less than or equal to α it is possible to reject the null hypothesis, allowing to infer that a group 1 has a larger response than group 2, in case of being one-sided test.

In this case to calculate the significance level it was used an asymptotic method.

2.3 Study Area

The study area was selected due to a non-significant human pressure influence on the mangroves on North of Australia (MangroveWatch, 2013). As it was mentioned before, mangroves in this area are affected mostly due to natural factors such as storminess, rainfall, temperatures, among others. Moreover, Northern Australian mangroves present a wider range of species, dense and luxurious forests (FAO, 2007). And it is known to be intensely affected by ENSO (McBride and Nicholls, 1983). Thus, make it an excellent site for the purpose of this study; its limits are within 110°E and 153°E longitude and 10°S and 25°S of latitude (Figure 3).

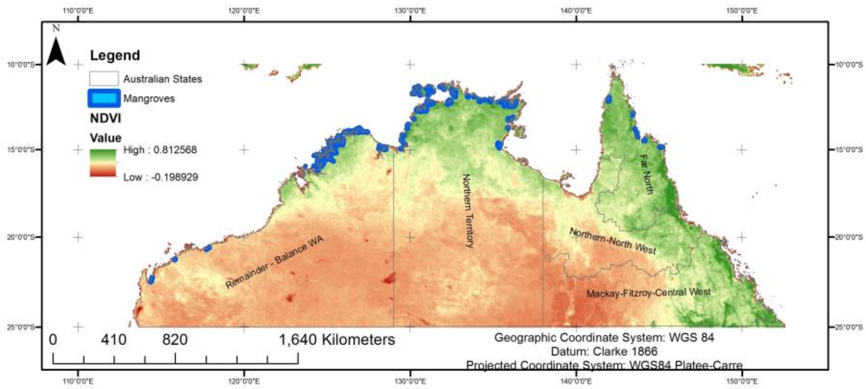

Figure 3-Study Area and Mangroves location.

2.4 Data Available Used

The majority of the datasets were extracted directly from IRI Data Library and are briefly described on the table 2 and on chapter 2.3.1. Additionally, other two ancillary datasets were used. First, the mangrove vector dataset which was provided by the Department of Geoscience under Australian Government domain. This dataset is a compilation of different aerial photography expeditions, over Northern Australia, being processed by the Defence Imagery and Geospatial Organisation (DIGO) within a scale of 1:50000, projected on WGS84 coordinate system (Burke et al., 2001). Simultaneously, it was used a coastline shapefile within a scale 1:1 million scale available projected on the WGS84, also produced by Geoscience Australian Department.

2.4.1 Data Description

2.4.1.1 SST

The NOAA OI v.2 SST monthly dataset with 1° of spatial resolution is based on a linear optimum interpolation of weekly values into daily values. Posteriorly monthly values were extracted through the averaging of daily values.
Mostly, this dataset compiles *in situ* data (buoys and conservation ships values), satellite data, and ice cover simulated data (Reynolds et al., 2002). A product with such coarser spatial resolution although with a high temporal coverage presents some limitations, which will induce a level of uncertainty to our results.
The most relevant limitation is the effect of a residual globally averaged difference, around 0.05°C and recurrent within a period of

ten years which was not successfully corrected on this product, therefore needs to be considered for this study, once here are covered 24 years.

2.4.1.2 RAINFALL

Several products concerned to rainfall were available on the IRI/LDEO Data Library and it was performed a comparison between two different ones for our study area and period defined; the two products are rain gauge- based observations and are displayed below (Figure 4).

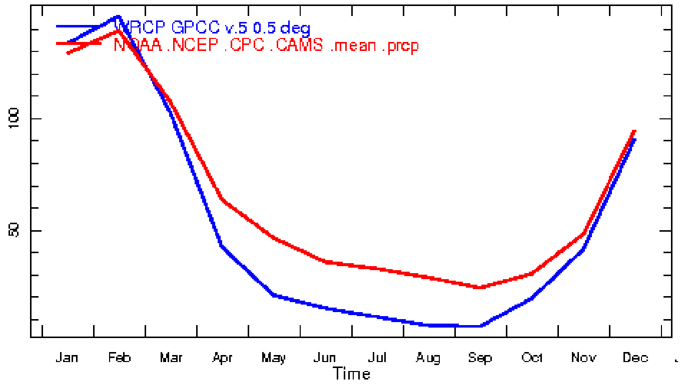

Figure 4 –Comparison between two different rainfall products rainfall.

One of the main issues related to rainfall products it is the uncertainty associated to the background surface, demanding a different approach for estimations on land and ocean (Gruber and Levizzani, 2008). It is known that gauge analyses products such as GPCC are known for facing significant problems such as the influence of aerodynamics effects, mostly affecting light and solid precipitation, thus leading to an underestimation of precipitation on its occurrence areas (Gruber and Levizzani, 2008; Rudolf et al., 2010). Despite both products show similar trends, CAMS product appears to overestimate the total precipitation amount for our study area and period, according with Bureau of Meteorology information for a similar period and location as it prove on figure 5 (Bureau of Meteorology, 2013; Ropelewski et al., 1985). Therefore the GPCC Full Product Version 5 was the selected product for our study case.

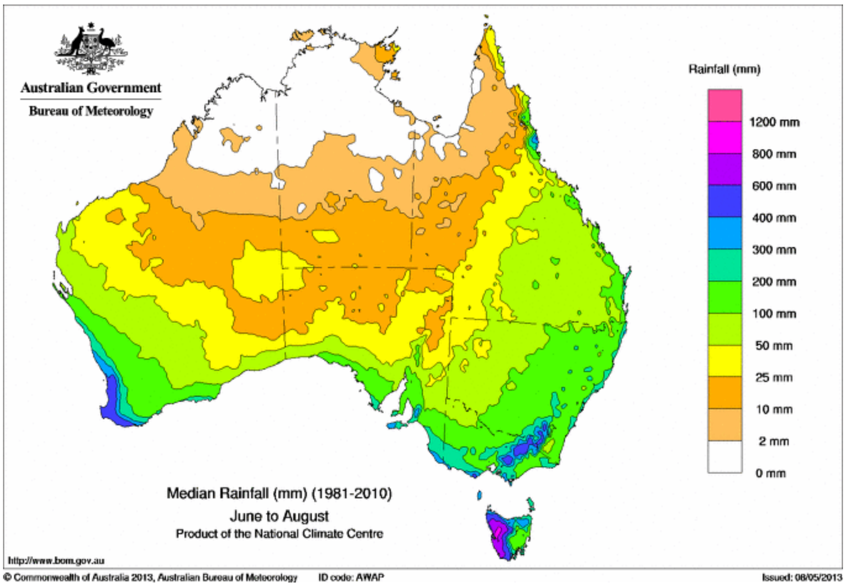

Figure 5- Median rainfall (mm) for all Australia within the period of 1981-2010 (Bureau of Meteorology, 2013)

2.4.1.3 NDVI

The NOAA AVHRR NDVI product presents a spatial resolution of 8 km (0.07272728°) and a temporal coverage since 1982 until 2006. The NDVI values consist on 15 days composites and it has a daily frequency. It is the only product available to assess vegetation condition for such a long-time running series (U.S. Geological Survey, 2012). It is calculated using red and infrared bands through the formula NDVI = (NIR - RED)/ (NIR + RED), which for the case of NOAA AVHRR, NIR correspond to channel 2 and RED to channel 1 (Tucker et al., 2005).

NDVI index since is not a direct satellite measure; instead a result of a difference between two bands. For such calculation it is necessary to perform band calibration. It is also known that satellite data is often affected by the medium conditions. In the NDVI case, the effect of aerosols, water vapor, as well as cloud cover needs to be removed or minimized once it has a huge impact on NDVI final values. GIMMS used maximum NDVI values to solve the later problem since it reduces cloud cover. Besides the medium conditions it is necessary also be aware of the errors caused by the sensor specificities. Problems such as solar illumination angle and view angle were described and correct by GIMMS. It is important to mention that it was not possible corrected NDVI values affected by soil background reflectance on this product (Tucker et al., 2004; Tucker et al., 2005).

2.4.2 Data Available

Table 2- Datasets used on IRI/Data Library (Columbia University, 2012).

	OCEANO-GRAPHICAL	TERRES-TRIAL	ATMOSPHERICAL	
Variable	SST	NDVI	SOI	Rainfall
Spatial Resolution	1x1 Degree	0.07272727 Degree	1x1 Degree	0.5x0.5 Degree
Temporal resolution	Monthly	1-15 days	Monthly	Monthly
Period Available	1981-Present	1982-2006	1951-Present	1901-2009

Available In	IRI/LDEO	IRI/LDEO	IRI/LDEO	IRI/LDEO
Product Name	NOAA NCEP EMC CMB GLOBAL Reyn_SmithOIv 2	UMD .GLCF .GIMMS .NDVIg .global .ndvi	Indices SOI	.GCOS .GPCC .FDP .version5
Source	NOAA NCEP EMC CMB GLOBAL Reyn_SmithOIv 2	NOAA	CPC	WRCP

2.5 Research Approach

First of all, to choose a more efficient statistical procedure to measure the association between ENSO and NDVI on mangroves, different descriptive techniques were used for all the datasets. In general Spearman's Rank correlation revealed to be more effective than Pearson's correlation mostly due to a non-normal distribution presented on each variable. Although the main reason of this test was the important extreme climate events that occurred for the study period over Australia, which were strongly captured by Spearman's and poorly assessed with Pearson's once this it is sensitive to values that are considered outliers.

Two different approaches were used; firstly using rainfall as an indirect link between ENSO and mangroves NDVI. The rainfall as it was explained on chapter 1 it is an important requirement for mangroves growth, the latter is assessed through the use of NDVI. Secondly it was assessed the direct link between mangroves NDVI and an ENSO proxy; due to the lack of literature on which proxy would be more suitable to look for such an association, both SST and SOI were assessed, and SOI revealed better results. SOI and SST's role was chosen on this study mostly due to its influence rainfall distribution patterns that it is known to have an effect on NDVI. Though for example sea surface temperature is directly related to mangrove distribution.

All anomalies and operations that would be described further were executed using Ingrid Language available on IRI/LDEO Climate Data Library (Columbia University, 2012) and ArcGIS 10.1 .
Due to the large study area, covering the entire Northern Australia coastline, it was necessary proceed to a subdivision. That subdivision it was based on the boundaries presented by the FAO report (Bakun

et al., 1998). Consisting in the areas affected or not by ENSO warm events. As result we had two distinct areas, also coinciding with West and East of Northern Australia boundaries. The correlations coefficient is based on pixel level.

2.5.1 ENSO and rainfall association

Often, in order to understand the influence of ENSO in precipitation variability, it is used lagged correlations. Generally this period is around 5 months or longer (McBride and Nicholls, 1983; Ropelewski and Halpert, 1996). Taking that into consideration and following the season's definition used by McBride and Nicholls (1983) - Spring (September, October, November); Summer (December, January, February); Autumn (March, April, May); Winter (June, July, August) - seasonal averages were calculated over all the three datasets (SOIa, SSTa, Ra) for the 24 years period (1982-2006).

In order to find the strongest associations between rainfall anomalies over Australia and sea surface temperature anomalies on a global scale it was performed a correlation between Ra and SSTa.
The first step consisted on the rainfall anomalies restricted to West and East of Northern Australia region, respectively, with global SSTa for a lag period of three months. The aim was find the global associations between SSTa and Ra over Australia, on a worldwide scale. This step allowed to visualize the existence of relevant patterns occurring on the well-known Nino region, over the central Pacific (Trenberth, 1997). The reason why we have different global maps for both East and West Australia is associated to an IRI/LDEO language expression. Commonly the absence of spatial restrictions on SSTa allows to extract all the global SSTa patterns associated to, for example, rainfall anomalies that occur in West Australia. On a simplistic way it does reflect how and where the rainfall anomalies on West Australia are linked to global SSTa. Usually by applying spatial restrictions on SSTa, or even Ra we will see their effect locally and according with our chosen restrictions, which is the reasoning for a zooming on Nino Regions.

After the visualization of those patterns on central Pacific it was possible a zoom on Nino regions and assess the strength of each Nino regions on rainfall variability over Australia. By zooming into NINO region boundaries it is possible assess SSTAs magnitude and how it is distributed across the central Pacific. All this correlations were executed for all the seasons described above, both for western and eastern Australia.

The use of spatial restrictions on SSTa (Nino regions physical boundaries) allowed to execute a correlation with Ra, where it would be possible visualize the spatial explicitness all over Australia of such association, and which areas would be more affected by ENSO or not.

The warmer SSTa over the central Pacific are divided by regions. Nino 1 is the area defined by 80W-90W and 5S-10S, Nino 2 by 80W-90W and 0S-5S, Nino 3 by 90W-150W and 5N-5S, Nino 4 by 150W-160E and 5N-5S, Nino 3.4 by 120W-170W and 5N-5S (Trenberth, 1997).

Noteworthy the importance of anomalies, described here as deviations from a reference value or a long term mean. Particularly used on this study once it is clearly representative of the changes occurring across the time; thus, enhancing relevant patterns more accurately. (Ronghui and Yifang, 1989).

In SOI's case, it was computed the anomalies on IRI Data Library and once it is an index it was previously spatially restricted to Tahiti and Darwin regions. Rainfall anomalies were under similar restrictions to those mentioned above.
As a result it was possible to visualize the spatial variability of the relationship between these two variables all over the study area.

2.5.2 Mangrove Greenness and Rainfall association

2.5.2.1 Time-Lag Selection

Similarly to step 2.5.1 it was computed a lagged correlation among NDVI anomalies and rainfall anomalies. Beforehand, a broader definition of season was used. This subdivision focus mainly on the extraction of NDVIa values for the months that represent the peak of wet season (January and February); and similar procedure was done for dry season (August-September). On the other hand, the different Ra periods were chosen dependent on the lag selection. These Ra periods were averaged over three months based on a similar approach used by Richard and Poccard (1998) where it were considered the average multimonth rainfall of the preceding months from the NDVI month selected as reference (Richard and Poccard, 1998).
NDVI anomalies over a monthly mean and were computed on IRI/LDEO Data Library and correlated with rainfall anomalies, using

Spearman’s Correlation, by virtue of a skewed distribution of each dataset.
The rainfall product selected was GPCC with a 0.5° resolution, and it was correlated with the NDVI, this one with a spatial resolution of 0.072728°, from NOAA.
Posteriorly it was compared the lag’s choice based on literature review and study context (Nicholson et al., 1990; Richard and Poccard, 1998).

2.5.2.2 Mangrove NDVI Pixel Extraction

After proceeding with time lag selection, a further step was added to this procedure in order to extract correlation values of the pixels which were largely mangroves for an ENSO and Non- ENSO area. Firstly, it was executed a correlation between NDVIa for all Australia and Ra. Though, the main interest it was to extract all the feasible pixels that could be considered purely mangroves. A closer look to figure 3 allowed to visualize that mangroves are narrow bands and distributed across all northern Australia. Due to their spatial distribution it was necessary to select valuable criteria in order to chosen significant mangrove pixels adjusted to such a coarse scale (8km). In order to be able to execute this step it was computed three ratios. The first one consisted on creating a water ratio, to be able to select all pixels, that had more than 20% covered by water. The second one consisted on a mangrove fractional coverage ratio, by selecting all pixels where were found more than 10% of mangroves. At last it was created an “other vegetation ratio”, with a threshold of less than 20% of influence on the pixels. It is important to mention that such thresholds were not previously defined by the literature but instead consisted on several attempts to achieve a feasible number of pixels.
The final output of such selection was the total amount of 10 pixels for both areas affected by ENSO and non ENSO. Additionally, it is relevant to mention that the maps presented on chapter 3, only show the spatially explicitness of an association between NDVIa and Ra over Australia, and they do not express exclusively the response of mangroves to rainfall anomalies. Instead such pixels will be extracted on table format and analyze accordingly.
On the 10 pixels selection it was applied another filtering process to analyze if indeed, all the pixels would be representative of mangroves NDVI. The possibility of other vegetation ratio being more expressive than mangrove ratio it is known to affect the NDVI values and it was here proved, thus invalidating two more pixels; thus the final result

consisted on the total of 8 pixels, 4 for each ENSO and Non-ENSO area.
Table 3 presents the critical values for a Spearman's Correlation 90% confidence level (one-tailed test) and the specificities of the dataset relevant for this correlation (Figure).

Table 3- Dataset used for NDVIa/Ra correlations.

RAINFALL	GPCC
Temporal Resolution	(1982-2006)
Spatial Resolution	0.5°
NDVI (AVHRR)	0.07272728°
Degrees of freedom	24
Spearman Critical Values	0.271

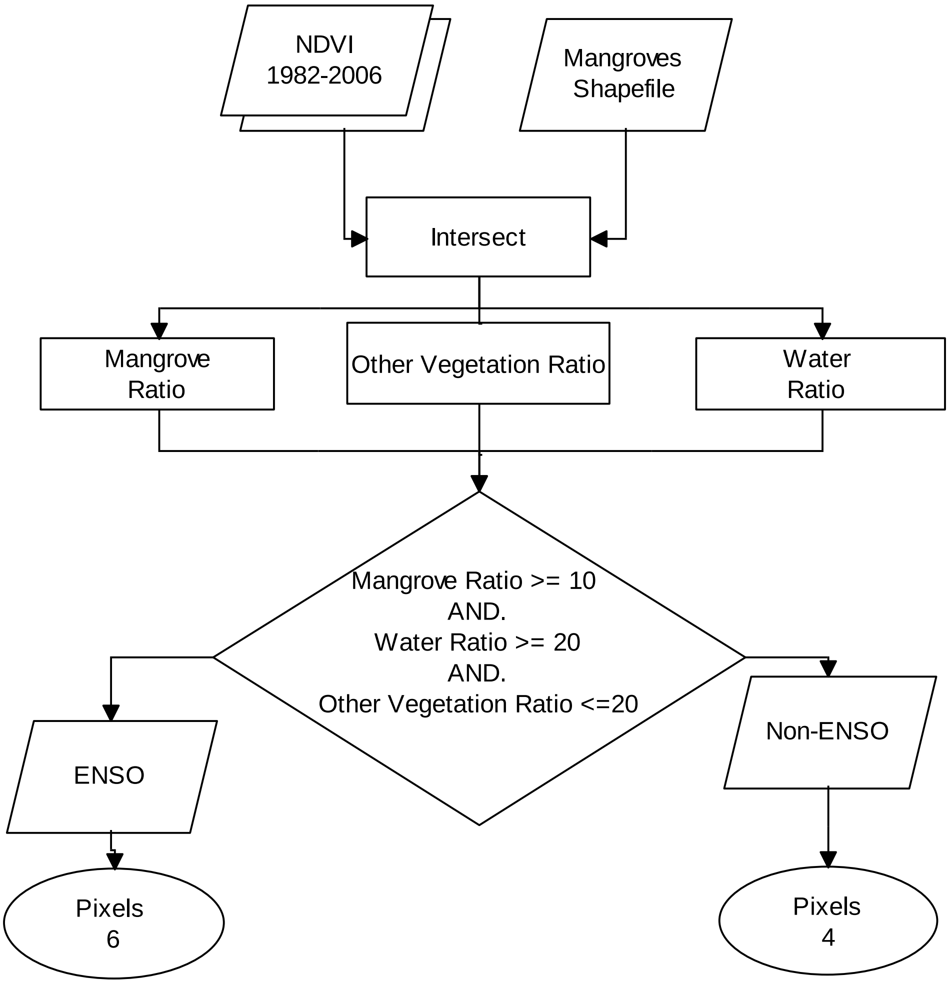

Figure 6- Pixel selection criteria and final output.

2.5.3 Mangrove greenness and ENSO proxies association

2.5.3.1 Time-Lag and Proxy Selection

An approach to test how strong the correlation between NDVIa and ENSO was, consisted on the use of different ENSO proxies. Since it was unknown which proxy would present better associations, both SSTa and SOIa were tested. Simultaneously it was unknown as well, the response lag of NDVI to both proxies, several attempts had been done and for lags exceeding 3 months it was possible to visualize a decrease on the correlation values (results not presented here). Similar procedure to 2.5.2.2 it was used then to extract the correlation values for each mangrove pixel for a Non-ENSO and ENSO area. Once more it is important to mention that maps on this step are merely informative, presenting the global association between NDVIa and SOIa for all the Australia, and later on will be used to extract mangrove individual pixels, which will presented on the format table and analyze accordingly.

At last it was computed Mann-Whitney test to assess if there was significant difference between mangroves greenness on a Non-ENSO and ENSO Area.

3. Results and Discussion

3.1 ENSO and rainfall association

3.1.1 SSTa and Ra association

It was performed Spearman's Correlation test, using Ra and both SSTa and SOIa, to assess the robustness of a possible association between these two variables. The results will be shown and discussed along this chapter.
It is essential understand the meaning of a negative or positive correlation on the context of this study. A negative correlation here it refers to a warming-up of SSTa's over the Central and Eastern Pacific associated to a rainfall below-average over the Northern Australia coastline, both West and East region.
The reasoning for such behavior arise from a weaken on the easterlies winds allowing the possibility of warmer temperatures rise over the central Pacific, in other hand a drop of the surface pressure on the central Pacific (SOI) occurs . The arisen of the warm air provoked by the warm sea surface temperatures over the Pacific will originate rainstorm occurrence on the eastern and central Pacific, where commonly El Nino originates. The occurrence of these phenomena will lead rainfall to an eastward movement caused by these warmer temperatures affecting mostly the countries on the western pacific which will experience then drought periods, which is the case of Australia.
Noteworthy that when a negative correlation between Ra and SSTa is here strongly represented by different blue tones, it is experienced simultaneously a strong positive correlation between Ra and SOIa herein represented by strong oranges and yellow colors, caused by their coupled interaction as it was already mention on chapter 1.

Meanwhile positive correlations between Ra and SSTa can have two different meanings. Firstly, that an above-average rainfall on Northern Australia is related to an above-average SST over the Pacific Ocean, or the reverse, a below-average SST over the Pacific is associated to drier conditions on the Northern Australia. Since our results represent a study over a period of 24 years and knowing previously that for this specific period the overall SST are warmer on the central Pacific (Bakun et al., 1998; FAO, 2007), we will rely on the first option.

The figures 7, 8, 9 and 10 here represented the global SSTa manifestations related to rainfall anomalies that occur both on West and East Australia, for all the seasons. Such correlation product allows to infer the existence of significant associations patterns over the central Pacific. Therefore that is the reasoning it was executed for each subdivision of the northern Australia (West and East) which are differently impacted by ENSO, according with Bakun *et al.* (1998) for all the seasons. It is important to mention that the global maps represent IRI/LDEO language. And they express merely associations patterns.

Figure 7 and 8 enhance the location of the strongest associations between Ra, West and East of Northern Australia, and the global SSTa according with previously confidence of level established. Though, due to our interest on ENSO phenomenon, this study will focus mainly only in the associations visible on NINO regions. A closer look allows visualize that the two figures show significant differences according with season and area within the NINO regions. Which nature would be further investigated.

For an instance it is possible to see how robust is the negative association on austral spring (SON) on the East Australia, corroborating with the results achieved by McBride and Nicholls (1983) where spring was stated as the strongest season (Figure7). A similar association, though, moderately weak, is seen still on East Australia for the autumn (MAM) season (Figure 8). Despite of these two strong associations, there are others less clear though significant for our study. Hence it was performed a zoom on the NINO regions and applied a box based on Trenberth (1997) NINO limits boundaries (Figure 9 and 10) to extract those patterns.
All the images presented on this study were masked with a moccasin color for non-significant values. On this analysis a 90% significance level for 24 degrees of freedom was used and corresponds to 0.271.

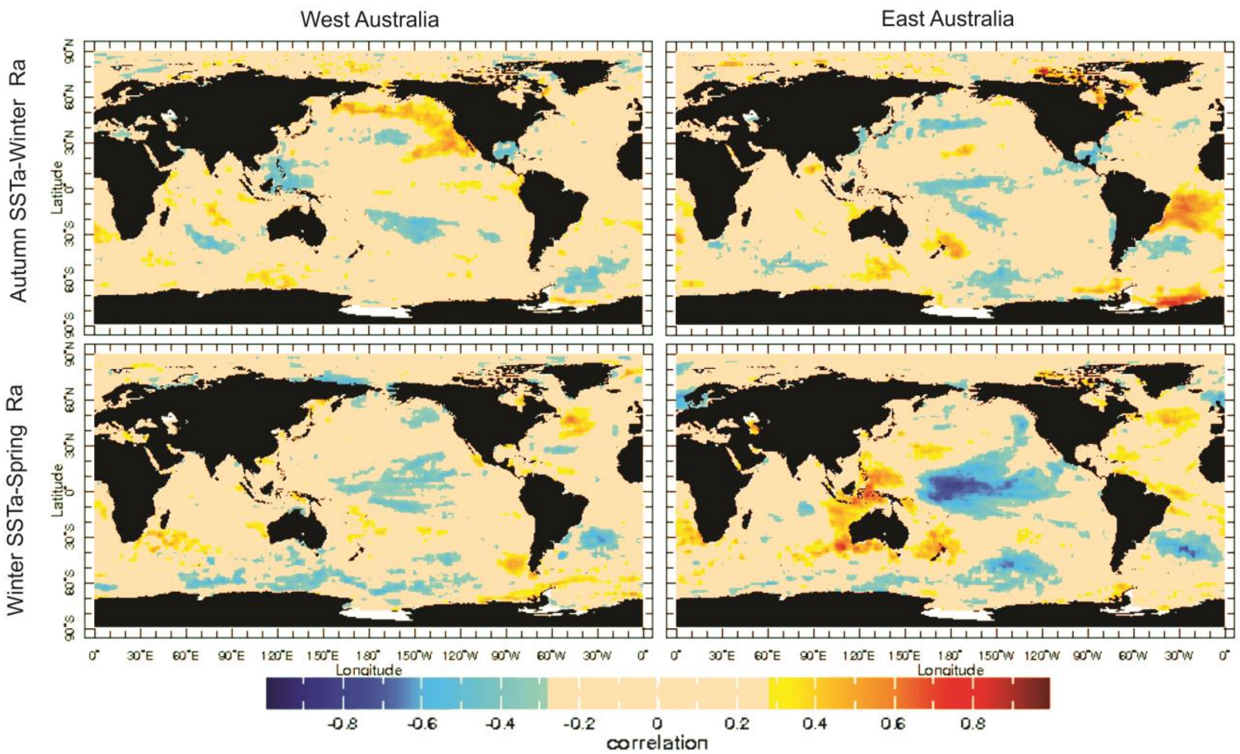

Figure 7- Autumn SSTa-Winter Ra and Winter SSTa- Spring Ra for East (Left) and West (Right) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

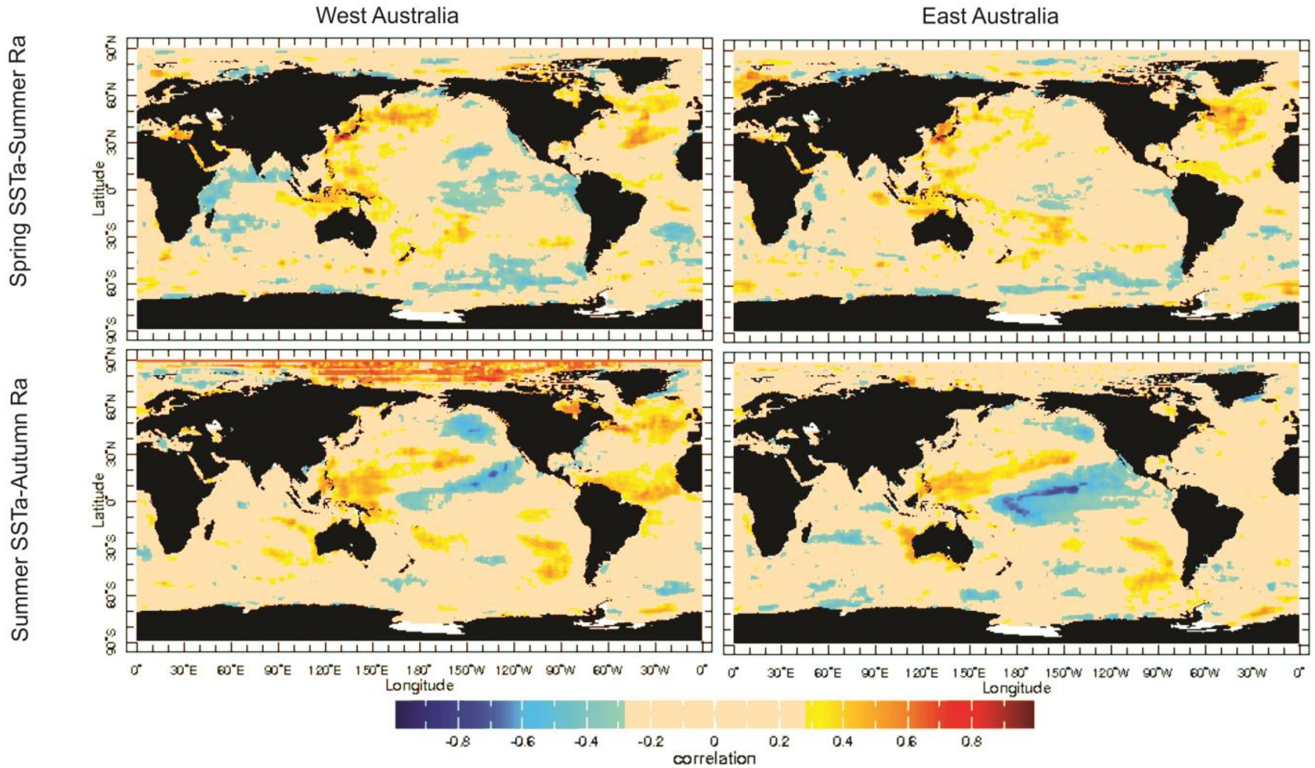

Figure 8- Spring SSTa-Summer Ra and Summer SSTa- Autumn Ra for East (Right) and West (Left) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

The results of Figure 9 exhibit an interesting association for the winter season, more specifically, a scatter positive correlation within Nino 3 and 3.4 boundaries on West Australia Region; whilst East Australia exhibits a moderate/ weak association with NINO 4 region. It seems that only West Australia during the Spring season contradicts Ropelewski and Halpert (1987); all the other images are on agreement with the statement that ENSO episodes are associated to dry periods especially on Northern Eastern Australian Region (McBride and Nicholls, 1983; Ropelewski and Halpert, 1987; Wang and Hendon, 2007).
This positive relationship reflects the exclusive role of Pacific Ocean SST's and it doesn't take into account other possible and maybe more important drivers to rainfall variability over the West Region on the winter season (Ashok et al., 2001; Brönnimann et al., 2007).

On other hand, Figure 10 shows a weakest association between rainfall anomalies over Northern Australia for the summer season with NINO 3.4 regions, reinforcing the McBride and Nicholls (1983) findings.
On a global perspective it is clear the prevalence of two strongest seasons, spring and autumn, which are strongly associated to SST's over the Pacific Ocean. However, a general overview of all the figures allows to see that the majority of the associations, with exception the winter season on west region, are mainly on NINO 4 and NINO 3.4 regions and defined by a negative association with rainfall, thus with different strengths. According with Wang and Hendon (2007) the dry periods seen on this figure (Figure 10) are not only associated to the magnitude of the SSTa related to the NINO box influence but also depends on the shifting along the west-east direction of each ENSO event. Hence, it was proved that stronger SST's on the central pacific are more effective to induce El Nino events than SST's on eastern pacific (Wang and Hendon, 2007). Then, on the figure 9 and 10 it is possible to visualize that actually there are a clear westward shift of the SST's, concentrated on the central pacific with the exception of summer season.

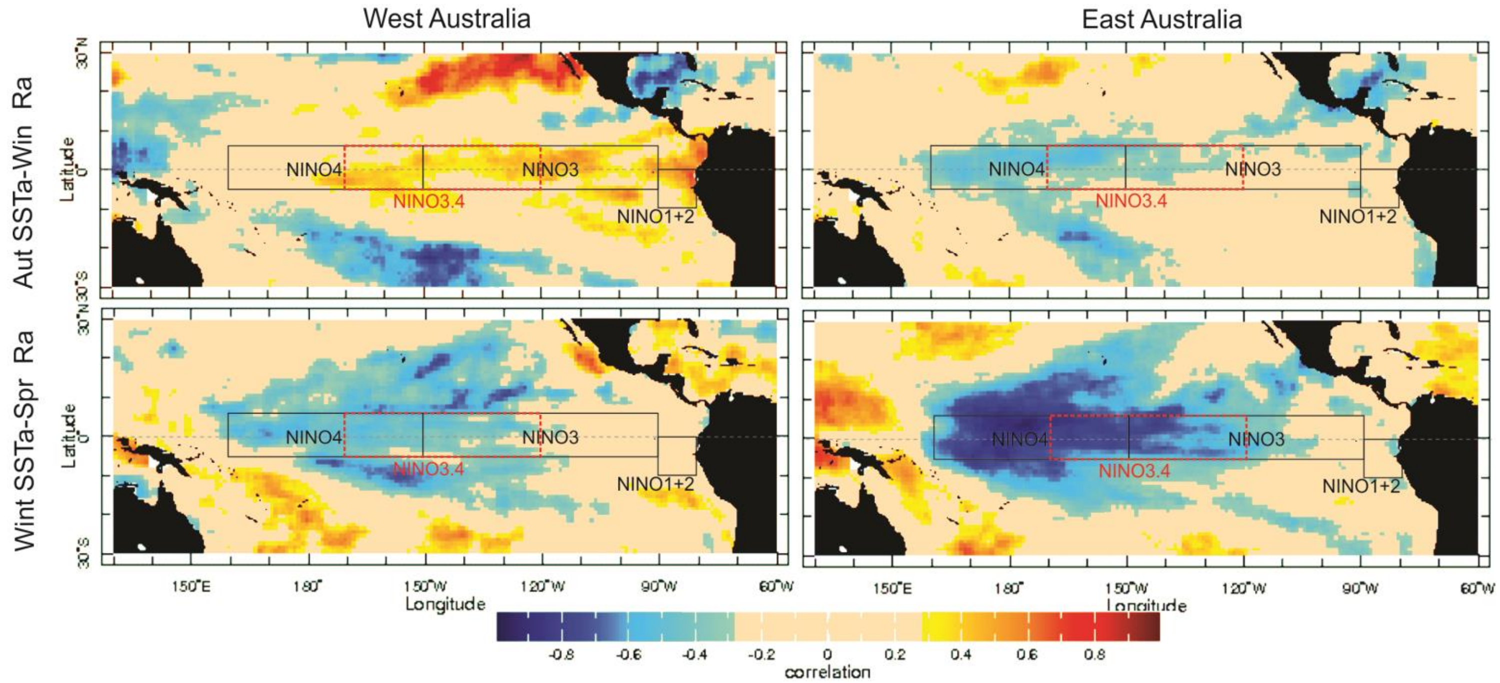

Figure 9- Autumn SSTa-Winter Ra and Winter SSTa- Spring Ra for East (Left) and West (Right) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

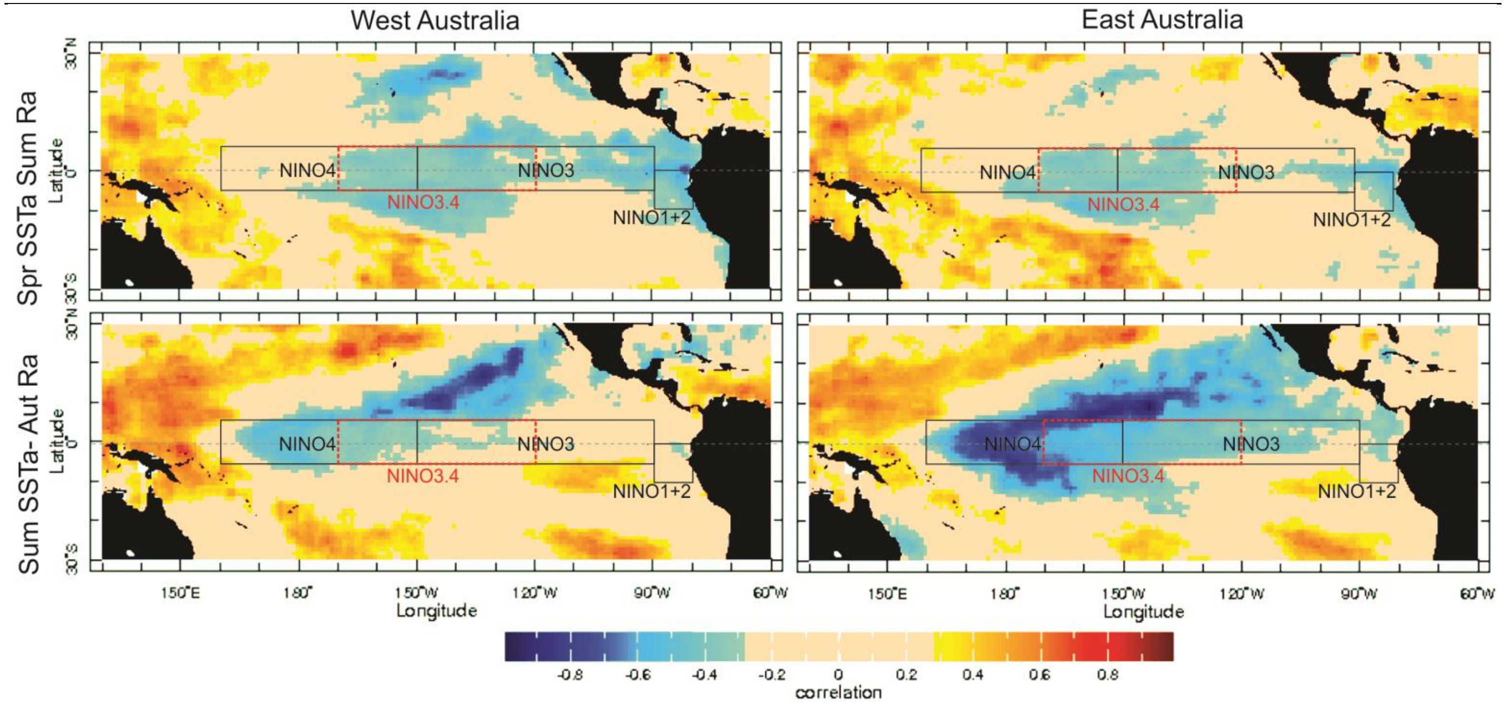

Figure 10 - Spring SSTa-Summer Ra and Summer SSTa- Autumn Ra for East (Right) and West (Left) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

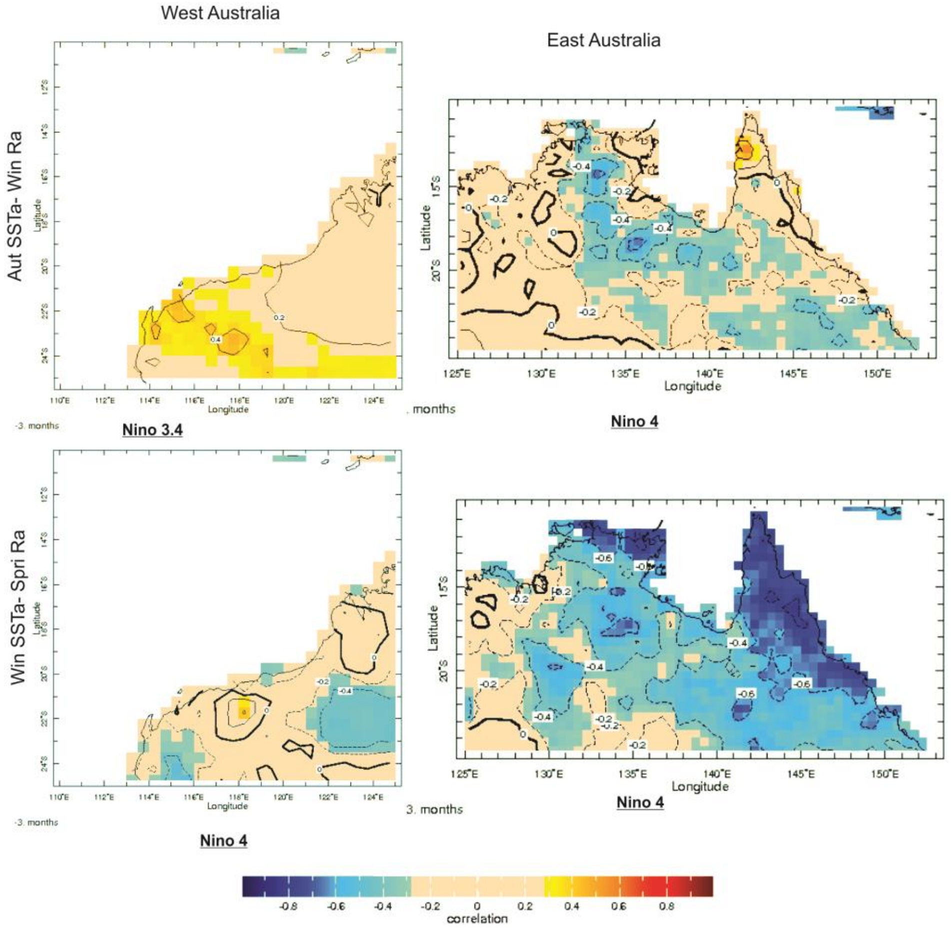

Figure 11- Autumn SSTa-Winter Ra and Winter SSTa- Spring Ra for East (Right) and West (Left) of Northern Australia according with most strong NINO region. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

For a better comprehension of the influence of NINO regions on the rainfall spatial variability on all Northern Australian territory it was reversed the variables dependency. Now it is possible comprehend how the positive association spread along the west region, being allocated mostly on hinterland regions. These values express a rainfall above-average along with warmer SST's over Pacific (FIGURE 11 and 12). In 1989, Nicholls performed a similar study on the influence of SST on winter rainfall, for a different period; comparatively with his findings, it is possible to infer that across the years, ENSO magnitude has increased its influence in a positive way on the Northern Western Australia.

On the other hand, also similar patterns were achieved, by Wang and Hendon (2007), for the SON season, agreeing both on the spatial distribution and intensity of the SSTa association with rainfall on all the Australian territory.

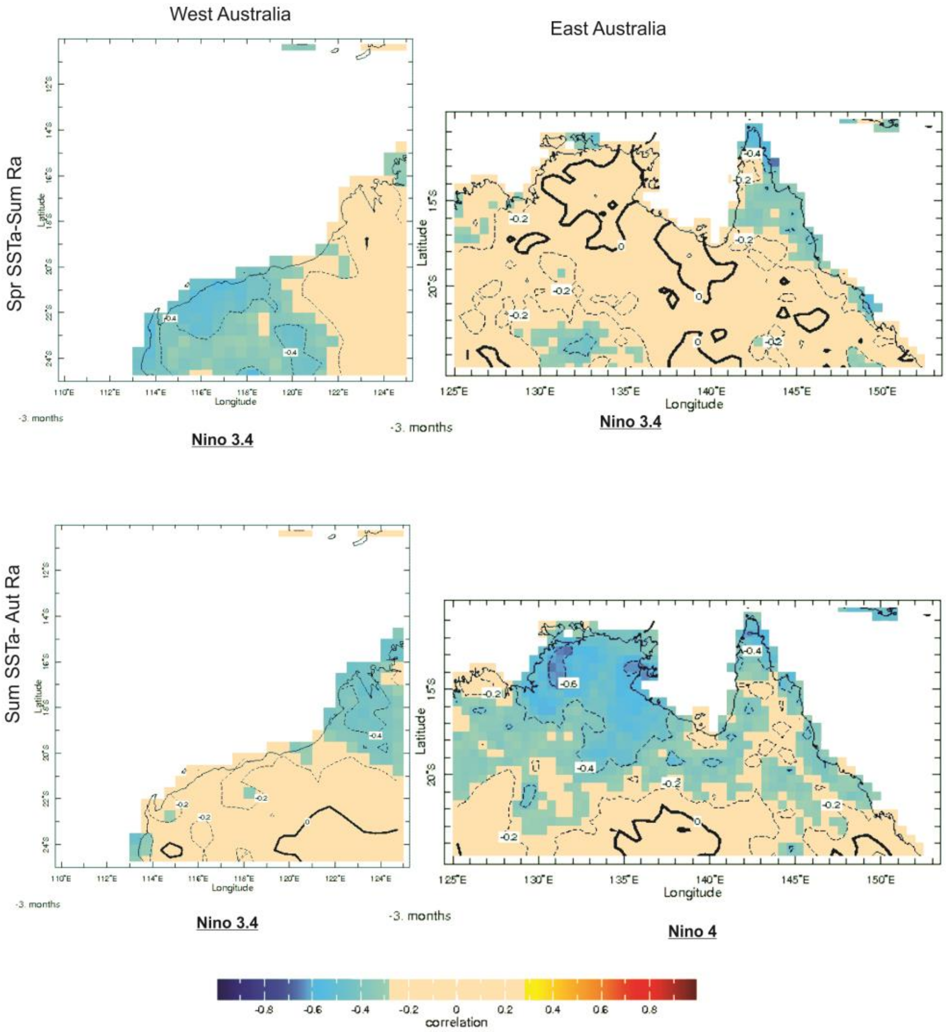

Figure 12- Spring SSTa-Summer Ra and Summer SSTa-Autumn Ra for East (Right) and West (Left) of Northern Australia according with most strong NINO region. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006).

SOIa and Ra association

In order to fully understand the impact of ENSO on our study area, it was also assessed the association between SOIa and rainfall variability. Similarly approach to the SSTa was computed and the results are shown above (Figure 13 and Figure 14). Positive associations in this case are related to less than average rainfall with below-average surface pressures.

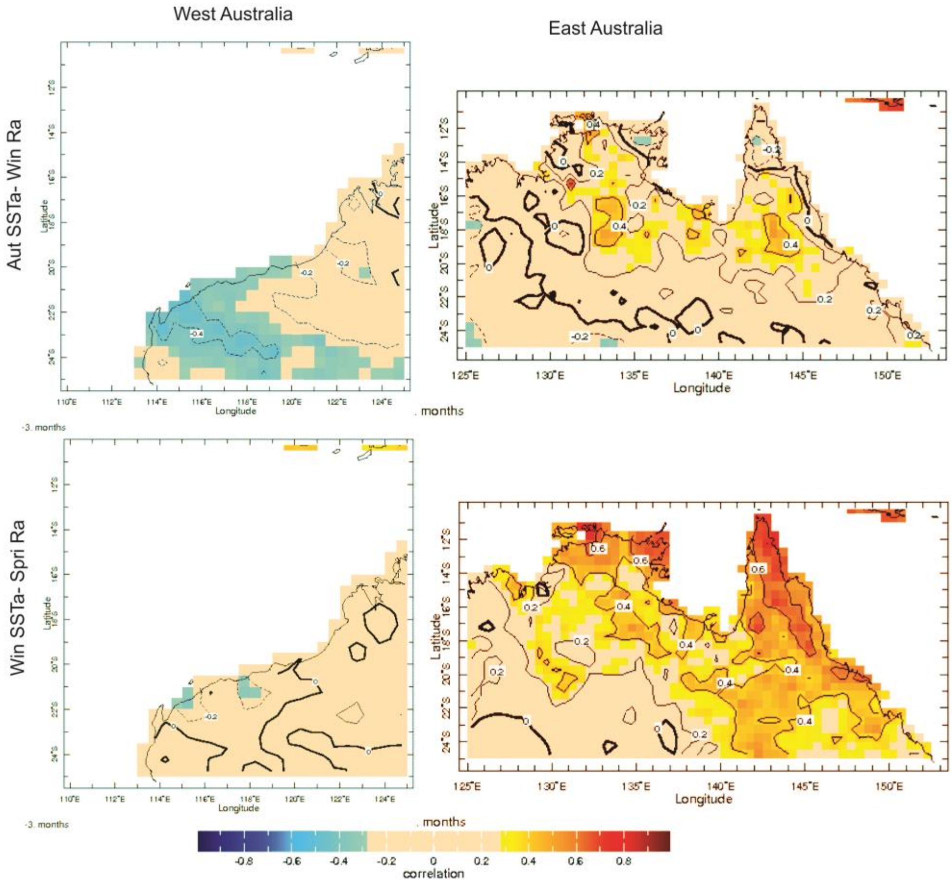

Figure 13- Autumn SOIa-Winter Ra and Winter SOIa- Spring Ra for East (Right) and West (Left) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

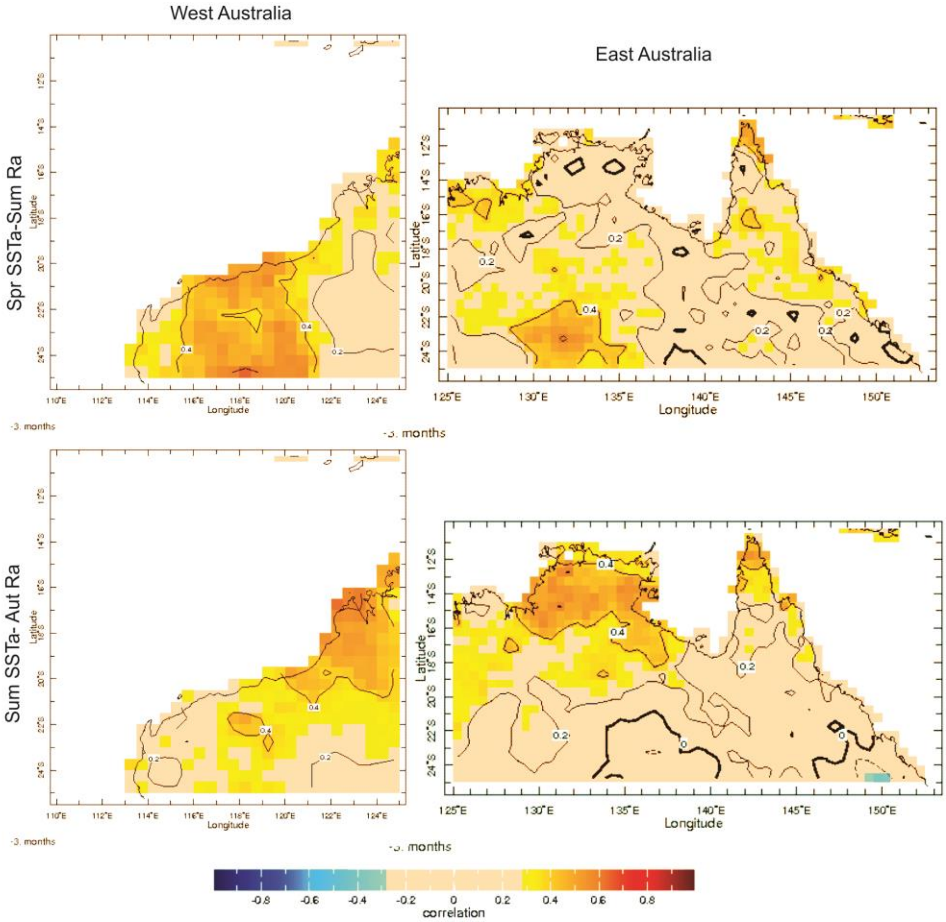

Figure 14- Spring SOIa-Summer Ra and Summer SOIa-Autumn for East (Right) and West (Left) of Northern Australia. For a 90% confidence level with 24 d.f. Spearman's Correlation 0.271) – (One tailed for a period between 1982-2006)

According with McBride and Nicholls, 1983, there was a distinct seasonal cycle on the correlations within the period of 1932 and 1974 between SOI index, therefore denominated by Troup Index, and rainfall (McBride and Nicholls, 1983). The same seasonal responsive behavior of rainfall to SOIa it is now less clear by looking at correlation absolute values on Table 4 than the one used by McBride and Nicholls. On the other hand, Figure 14 shows indeed that spring season has the strongest association, with a robust positive correlation located at north and eastern of Australia coastline, thus corroborating with McBride and Nicholls's results. In addition, the same authors also presented summer as the weakest season, which it does not occur for our study period. Instead, the winter season presents the weakest association. A positive correlation in figure 13 and 14 is representative of a below average sea level pressure in the tropical Pacific associated to a below average rainfall in Northern Australia.

Table 4 - Correlation coefficients for 90% confidence level with 24 d.f. between SOIa and Ra for all Northern Australia.

SOIa	Ra	Correlation
Mar-May	**Jun-Aug**	**0.04**
Jun-Aug	**Sep-Nov**	**0.26**
Sep-Nov	**Dec-Feb**	**0.24**
Dec-Feb	**Mar-May**	**0.23**

As it would be expected, SSTa and Ra correlation show opposite patterns, comparatively with SOIa and Ra, due to its coupled-interaction nature. Commonly, when SSTa are warmer on the central Pacific the sea level pressure anomalies are below average in the Pacific, influencing a weaken of the trade winds that blow from Eastern Pacific then resulting on a decrease of rainfall amount on Australia. Looking at Figures 11 and 12 where are represented correlations between NINO regions, with better performances, and rainfall anomalies, it is possible to assess the spring rainfall season as the strongest association for East Australia on SON season (-0.42). The tables 5 and 6 present the respective correlation absolute values between NINO regions and rainfall anomalies, for East and West Australia.

This robust negative association centered on north and eastern Australia is justifiable because, according with BOM, (2010), winter/spring period still covers large zero rainfall amounts in ordinary years despite being considered the pre-monsoon season (Bureau of Meteorology, 2010).

Table 5- Correlation coefficients for 90% confidence level with 24 d.f. between NINO Regions SSTa and Ra for West Northern Australia.

West	*NINO Regions*			
Season Ra	**1+2**	**3**	**3.4**	**4**
JJA	0.21	0.16	0.20	x
SON	x	x	-0.10	-0.14
DJF	-0.23	-0.27	-0.28	x
MAM	x	x	-0.17	-0.17

Table 6 - Correlation coefficients for 90% confidence level with 24 d.f. between NINO Regions SSTa and Ra for East Northern Australia.

East	*NINO Regions*			
Season	**1+2**	**3**	**3.4**	**4**
JJA	x	x	x	-0.17
SON	x	x	-0.34	-0.42
DJF	x	x	-0.14	x
MAM	x	-0.16	-0.20	-0.28

So in agreement with other studies (Ropelewski and Halpert, 1987; Wang and Hendon, 2007), it is possible to state that warmer SST anomalies on Pacific are intrinsically associated to drought conditions on North Eastern Australia. Noteworthy, that the correlations analyses reflect an overall pattern of 24 years-period reinforcing the idea that typically, winter/spring seasons, experience below average rainfall therefore strongly associated to El Nino events.
Contrarily to Risbey *et al.* (2009) statements that SOI presents better associations with rainfall.

3.2 Mangrove greenness and rainfall association

3.2.1 Time-lag Selection

On table 7 it is expressed the different possibilities explored to assess the relationship between NDVIa and Ra. It presents the NDVI months chosen as reference months and its correlation with the cumulative rainfall that precedes that reference month. Such step was performed for the two months with highest and lowest rainfall association between NDVIa and Ra to assess which would perform better. A Spearman's correlation was applied with a 90% confidence level based on a multimonth rainfall anomalies and a NDVI anomaly for a reference month. The figures 14 and 15 were based on the strongest seasonal association.

Table 7- Spearman Correlations for 90% confidence level using a Multimonth Ra and NDVIa.

NDVI	MULTIMONTH RAINFALL	LAGS IN MONTHS	NON-ENSO	ENSO
Aug	**Jun-Aug**	**-1**	**-0.11**	**-0.09**
Aug	**May-Jul**	**-2**	**0.04**	**0.08**
Sep	**Jul-Sep**	**-1**	**-0.06**	**-0.09**
Sep	**Jun-Aug**	**-2**	**-0.13**	**-0.13**
Jan	**Nov-Jan**	**-1**	**0.40**	**0.41**
Jan	**Oct-Dec**	**-2**	**0.27**	**0.27**
Feb	**Dec-Feb**	**-1**	**0.15**	**0.23**
Feb	**Nov-Jan**	**-2**	**0.22**	**0.20**

According with some authors, multimonth rainfalls present better associations with NDVI, once the NDVI does not respond directly to rainfall but to soil moisture (Nicholson et al., 1990; Richard and Poccard, 1998). Based on the figure 3, it was possible assess the peaks of wet season and dry season and once there were only slightly differences between the months with lowest/highest rainfall amounts, both were tested. Thus, only those with highest association will be displayed, for both ENSO and Non-ENSO regions.
This study focused on the assessment of the seasonal sensitivity of NDVI to rainfall, and as we may see, wet season for a -1 month lag,

presents for both Non ENSO and ENSO area, the highest values. These results consisted with the findings by Richard and Poccard (1998) and Nicholson *et al.* (1990) that multimonths rainfall preceding NDVI has better performance.

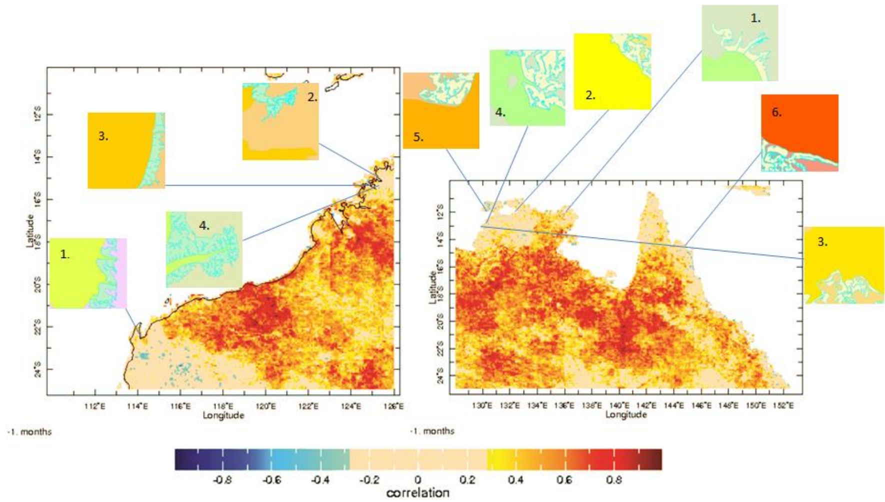

Figure 15- Wet Season: NDVIa (Jan) vs. Cumulative Ra (Nov-Jan) Spearman 90% 24 d.f (Left-Non ENSO; Right (ENSO)) (Box- Mangroves pixel extraction (Mangroves represented by blue outline))

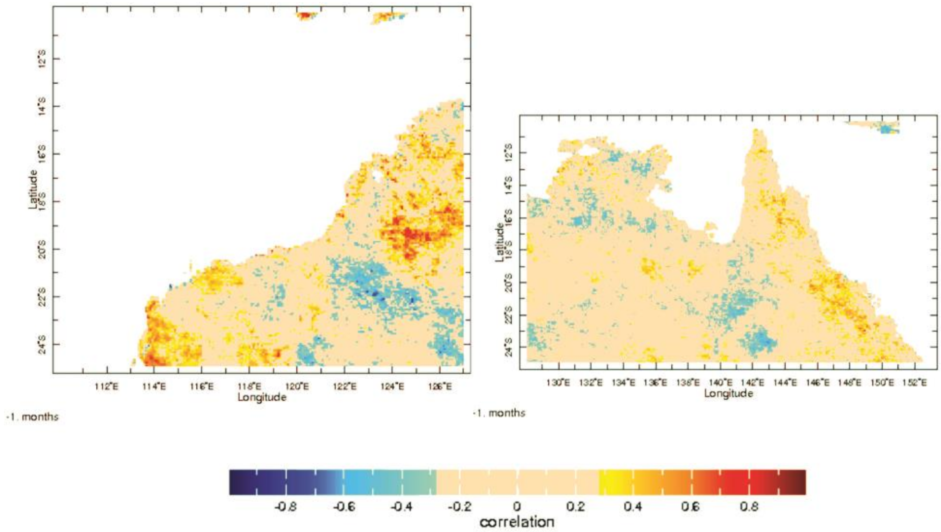

Figure 16- Dry Season: NDVI (Aug) vs. Cumulative Rainfall (Jul-Sep) Spearman 90% 24 d.f.

Figure 15 here presents the mangroves pixels mentioned on the 2.5.2.2 and their spatial distribution over Australia for a ENSO and Non ENSO area.
Through the figures 15 and 16 it is possible to understand the spatial variability of Ra and NDVIa for both seasons. A positive association reflects NDVI values above-average as a response to excessive rainfall and it is herein represented by oranges, reddish colors. Curiously, on the wet season period on the ENSO and Non-ENSO area, large portion of the coastal areas show an almost non-existent response of NDVI to rainfall. However, both areas show that hinterland vegetation has a very robust response to rainfall. It is important understand that, commonly NDVI values on coastal areas are difficult to assess due to the mixed nature of the pixels, which are largely affected by the water reflectance (Maselli, 2004; Nicholson et al., 1990; Richard and Poccard, 1998).Other possible explanation is the indirect response of NDVI to rainfall. Instead it is expected that rainfall affect directly the soil moisture, therefore affecting NDVI. In some other studies proved that for precipitations greater than a certain range, the soil moisture is not anymore a limiting factor and we would assist to slightly changes on NDVI induced by increase of rainfall, which is believe to be the reason for such a neutral association on the coastal areas, though it was out of the scope of this study find such reasons (Nicholson et al., 1990).
Figure 16 on other hand, exhibits a scarce and rare response of NDVI to rainfall during dry season.
Encompass this findings with previous ones (chapter 3.1.1) some interesting facts arisen. For an instance, relating the results found on figure 15 for the ENSO area with the outcomes found on figure 11 (SSTa) and 13 (SOIa), the moderate association between NDVI and rainfall on the peak season does not match with the weak association ENSO and rainfall experienced on summer season. In other hand looking at the SSTa on the spring season on chapter 3.1.1 where is seen a below-average rainfall over the Eastern Australia it coincides with coastal areas on the figure 15 that do present a neutral association between NDVIa and Ra. Nevertheless it is known that ENSO along with IOD, affects mostly influence winter and spring season, open this result to other possible summer rainfall drivers (Cai et al., 2011; Risbey et al., 2009).

A closer look to the mangroves pixels though allow to infer different conclusions. Table 8 and 9 represented the correlation values for the mangrove NDVIa and Ra. Pink rows are the result of a filtering process mentioned on 2.5.2.2 and then will not be taken into account. Generally, NDVI is expected to respond positively to above-normal rainfall values. And by looking at table 8, during the wet season, we will that 75% of the pixels present a weak positive association for a Non-ENSO area and ENSO area. However mangroves are known to be halophyte communities and non- water limited communities, thus it would be expected a neutral association between rainfalls on mangroves greenness. And as we can in table 8 there are correlation values around 0. Table 9 in the other hand presents positive weak associations for all mangrove pixels in a Non-ENSO area and a not so clear sign of association for an ENSO area, not being possible to conclude either there is a relationship and if it is, what direction it takes.

Table 8- Spearman's correlation 90% confidence level between mangroves Pixels NDVI and Ra for the wet season (Pink- Unvalid pixels; Green-Mangrove pixels)

	Correlation	Mangrove Ratio	Other Vegetation Ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
	Non-ENSO					
1	-0.1	17.0	5.0	78.0	69072.6	11048158.9
2	0.1	10.0	0.0	90.0	77419.6	6541784.0
3	0.4	11.0	7.0	82.0	55209.3	7495405.9
4	0.0	40.0	0.0	60.0	215241.5	25932752.3
	ENSO					
1	-0.3	13	16	71	69639.9	8501908.9
2	-0.2	12	4	84	62425.5	8069084.5
3	0.3	12	7	81	104838.1	8253046.6
4	0.0	13	20	67	72764.5	8856152.9
5	0.1	29	17	54	109198.6	18850897.6
6	0.0	14	9	77	86345.1	9152947.2

Table 9- Spearman's correlation 90% confidence level between mangroves Pixels NDVI and Ra for the dry season (Pink- Unvalid pixels;Green-Mangrove pixels)

	Correlation	Mangrove Ratio	Other vegetation ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
	NON ENSO					
1	0.2	17	5	78	69072.6	11048159
2	0	10	0	90	77419.6	6541784
3	0.2	11	7	82	55209.3	7495406
4	0.2	40	0	60	215241.5	25932752
	ENSO					
1	0.3	13	16	71	69639.9	8501909
2	-0.1	12	4	84	62425.5	8069085
3	0.1	12	7	81	104838.1	8253047
4	0.1	13	20	67	72764.5	8856153
5	0.3	29	17	54	109198.6	18850898
6	-0.2	14	9	77	86345.1	9152947

The fact of the correlations in general be positive, for both seasons and both areas, just proves that we cannot reject the null hypothesis, assuming that NDVI is positively associated to rainfall. Though due to the small sample size such statements are lack of objectivity and it doesn't prove a relationship between rainfall and mangroves NDVI. It is also important mention the contribution of other vegetation types, once if they are in the same proportion than mangroves or even slightest inferior they still affect the mangrove NDVI, though it was not possible to exclude completely such influence due to the coarse scale from NOAA AVHRR.

3.3 Mangrove NDVI and ENSO association

3.3.1 Mangrove greenness between ENSO and Non-ENSO areas.

Simultaneously it was performed a Mann-Whitney test on the few pixels available in order to understand if there was a significant difference between means of mangroves greenness on an ENSO and a Non ENSO area it was performed a Mann-Whitney test. Mann-Whitney is a non-parametric test; therefore it does not base itself on a normal distribution. And it was ordinated according with its areas of occurrence (ENSO and Non-ENSO). The results are displayed below on table 13.

Table 10- Mann-Whitney Test ranks

Ranks

	Group	N	Mean Rank	Sum of Ranks
NDVI	ENSO	25	16.84	421.00
	Non-ENSO	6	12.50	75.00
	Total	31		

Table 11- Mann-Whitney Test

Test Statistics[a]

	NDVI
Mann-Whitney U	54.000
Wilcoxon W	75.000
Z	-1.050

Asymp. Sig. (2-tailed)	.294
Exact Sig. [2*(1-tailed Sig.)]	.314[b]

a. Grouping Variable: Group

b. Not corrected for ties.

According with Mann-Whitney assessment it can only be said that exist a difference between means of two samples if the significant value is smaller than the p-value. The results for the Mann-Whitney test for a 95% confidence level, in order to reject the null hypothesis, the sig. (0.294) should had been smaller than 0.05. Thus it was not possible reject the null hypothesis. Meaning that there are no differences between mangrove greenness on ENSO area and Non ENSO, though it has been possible prove the existence of already know relationship despite the rather weak association.

3.3.2 Time lag and ENSO proxy selection

The results of, which ENSO proxy reflected a strongest association to NDVI and which lag would be the more representative of such association, are displayed on the table 12.

Table 12- Spearman's Correlation for a 90% confidence level between SOIa and NDVIa for an ENSO and Non-ENSO region.

SOIa	SON		DJF		MAM		JJA	
LAG	**ENSO**	**Non ENSO**	**ENSO**	**Non ENSO**	**ENSO**	**Non ENSO**	**ENSO**	**Non ENSO**
0	-0.12	-0.07	0.15	0.12	-0.05	0.05	-0.09	-0.11
-1	-0.11	-0.08	0.17	0.12	0.11	0.17	-0.03	-0.06
-2	-0.10	-0.08	0.17	0.12	0.16	0.23	0.05	0.03
-3	-0.10	-0.06	0.14	0.09	0.19	0.24	0.09	0.10

A general overview on the table 12 allows to visualize that a 3 month lag is the one who presents the strongest associations, both SOIa and SSTa. It is no surprise that both proxies show the strongest associations on Summer NDVI and Autumn NDVI, consequences of the cumulative rainfall experienced on both areas during the wet season. Though it is visible that link between SSTa is indeed more fragile than SOIa for the similar reasons pointed on chapter 1. Based on this table it was possible select SOIa as the best proxy and therefore extracts its correlation with mangroves NDVI pixels (Table 13 and 14)

Following the same broader definition used on 2.5.2.1 it was selected only the best representation months for the wet and dry season ant it will be presented on the next figures.
A strong negative correlation on figure 17 and 18 represents an above-normal NDVI associated to a below average surface pressure (below-average rainfall) and it is represented by strong blue tones. In other hand, a positive association will rely that surface pressures above average are associated to above-normal NDVI, strong reddish tones.
Thus, looking at figure 17 it is possible to visualize a robust association on the Non- ENSO area, such pattern enhances the existence of other drivers for rainfall that have a positive impact on the western area of Australia. On the other hand, on a ENSO area it is possible to visualize on coastal areas a negative association, represented here by strong blue tones. Such pattern it is unexpected once it below-average pressures (SOI) are associated to less rainfall and it was not expected an above-normal NDVI. Such abnormal pattern would be clearer on a spring season, figure 18.

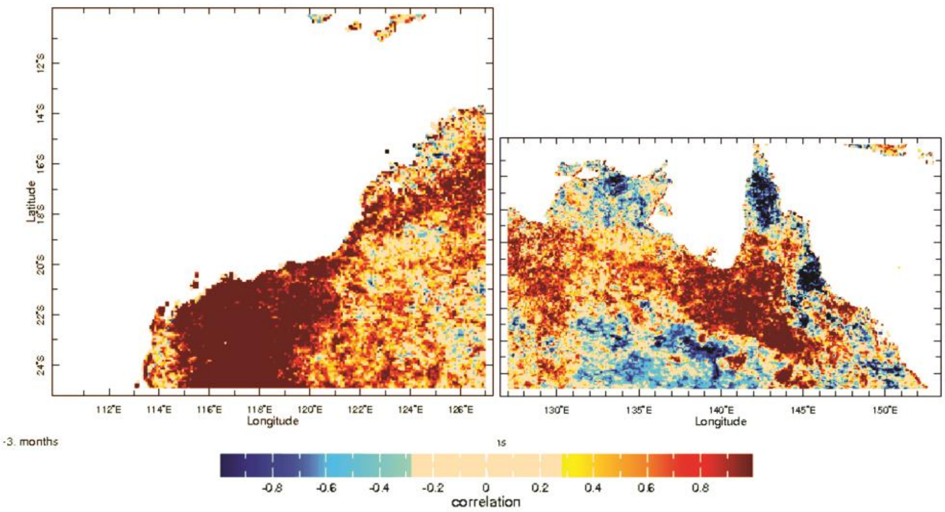

Figure 17- SOIa and NDVIa correlation for the MAM NDVI season for a confidence of level 90% with 24.d.f.

Table 13- Spearman's Correlation for a 90% confidence level between SOIa and mangroves NDVIa for MAM season (Green- valid pixels; Pink- invalid pixels)

	Mangrove Ratio	Other vegetation Ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
NON ENSO					
1	17	5	78	69072.6	11048159
-0.2	10	0	90	77419.6	6541784
0.9	11	7	82	55209.3	7495406
-0.1	40	0	60	215241.5	25932752
ENSO					
-0.5	13	16	71	69639.9	8501909
0.5	12	4	84	62425.5	8069085
0.1	12	7	81	104838.1	8253047
-0.2	13	20	67	72764.5	8856153
0	29	17	54	109198.6	18850898
0	14	9	77	86345.1	9152947

Though looking closely to mangrove pixels it is possible to assess that SOI has a stronger effect on a Non-ENSO area than on an ENSO area; however the signal of such an association it is not clear enough. The ENSO area not presents consistency on its magnitude, although it presents only positive associations (table 13).

Meanwhile, on the spring season it is possible to visualize a strong negative association between NDVI and SOIa dominant on ENSO area, mostly on the coastal vegetation (figure 18). Once again such pattern it was not expected, suggesting then the existence of other limitating factor that influences NDVI besides rainfall. Although this study only took into consideration rainfall as main factor on changes on mangrove greenness, it is know that temperature it also exerts a strong influence on vegetation growth and it has been assessed its role on other studies for different types of vegetation. (Wang et al., 2001).

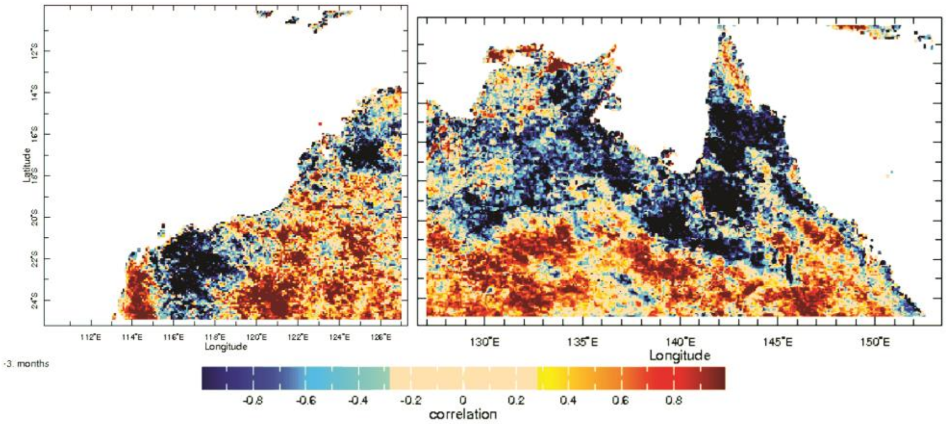

Figure 18- SOIa and NDVIa correlation for the SON NDVI season for a confidence of level 90% with 24.d.f.

It was possible to extract from figure 18, representing here the correlation values between SOIa and NDVIa, the mangrove pixels. The tendency for the SON season has been majority negative, presenting stronger associations that those extracted from chapter 3.2.1. Unexpectedly once more it was achieved negative anomalies meaning that for higher than normal pressures (higher rainfall amounts) are associated above-normal NDVI.
Such abnormal patterns, such as negative associations when what are expected are positive ones, suggest the presence of other factors that along with rainfall affect positively the mangroves greenness. One of the main limiting factors for vegetation growth is temperature, which was not assessed on this study but that is known for its direct effect on vegetation growth and its referenced on other studies as an important factor (Wang et al., 2001).

Table 14- Spearman's Correlation for a 90% confidence level between SOIa and mangroves NDVIa for SON season (Green-valid pixels; Pink- invalid pixels)

Correlation	Mangrove Ratio	Other vegetation ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
NON ENSO					
-0.1	17	5	78	69072.6	11048159
0	10	0	90	77419.6	6541784

-1	11	7	82	55209.3	7495406
-0.4	40	0	60	215241.5	25932752
ENSO					
-0.6	13	16	71	69639.9	8501909
-0.4	12	4	84	62425.5	8069085
-0.3	12	7	81	104838.1	8253047
0.4	13	20	67	72764.5	8856153
-0.1	29	17	54	109198.6	18850898
0.1	14	9	77	86345.1	9152947

4. Conclusion and Recommendations

4.1 ENSO and Rainfall association

The association between ENSO and rainfall was successfully proven for the different NINO regions, for a 90% level of confidence with 24 d.f., according with Spearman's Correlation. Thus, allowing to reject the null hypothesis, that there is no relationship between rainfall across the coastal vegetation (mangrove cover) on Australia and SST's over the Central Pacific. Therefore it was possible accept that ENSO events are negatively associated to rainfall on Northern Australia. Contrarily to Ashok et al. (2001), McBride and Nichols (1983) findings, the seasons with highest association were, in this study, spring and autumn (Ashok et al., 2001; Brönnimann et al., 2007; McBride and Nicholls, 1983). Other interesting achievement it was the unexpected above-average rainfall in the winter season seen on Western Australia. A possible explanation may be due to the existence other factors influencing rainfall variability on West Australia. Though for this study only ENSO was considered as the primary driver for Australia rainfall variability (Ashok et al., 2001; Brönnimann et al., 2007). Our conclusion is in agreement with the findings of other authors in that the SSTs in the Pacific Ocean by itself do not explain entirely the causality of rainfall variability in Northern West but are the main drivers for the East of Australia. The fact that similar studies do not achieved similar results may be due to the chosen period. Wang and Hendon (2007) stated that the SSTs variability differs from ENSO event to another. Therefore the chosen period it may reflect a pattern that takes into account different orders of ENSO magnitudes and its inter-annual variability. Also the majority of the recent studies had not considered lag correlations which is one of the explanations why there are not a consensus in relation to some patterns shown in this study that were not seen on unlagged correlation used by other studies.

4.2 Mangrove Greenness and Rainfall association

The association of mangrove vegetation greenness and rainfall it was here successfully proved, and it was rejected the null hypothesis, though it is not robust enough to establish a relationship between mangroves greenness and rainfall, due to the small sample size. Additionally it was possible to conclude that multimonth rainfall are a

feasible approach to prove the strength of this association (Richard and Poccard, 1998). Another finding was the time-lag response of vegetation on Northern Australia to rainfall, which was here proved to be robust for a one-month lag. Though some results remain unclear, mostly the weakest overall associations between rainfall and NDVI were surprising. Specially due to previous knowledge that Northern Australia presents strong positive association, R= 0.75 (Kawabata et al., 2001). A possible explanation it may be the use of Spearman's correlation, by applying ranks on anomalies values may affect the data expression *per se*, despite being the common statistic procedure for skewed data.
The absence of a clear NDVI response pattern coincident with the expected rainfall decrease it is not entirely surprising once mangrove communities on Northern Australia are known mostly for being species highly tolerant to saline conditions and that mangroves suitability requirements take into consideration other factors such as temperature, that influences as well its growth, and soil moisture, which is intrinsically associated to both temperature and precipitation and may be the explanation for the presence of a neutral association, though it was not tested such hypothesis on this study (Duke et al., 1998).

4.3 Mangrove Greenness and ENSO association

The smaller correlation (table 13 and 14) values achieved, allow to reject the null hypothesis and there stating the existence of a relationship between ENSO events and mangrove greenness. Though it is important to be aware of the weak pixels selection, which was found later on and it is not significant. Similar studies using such parameters could not be comparable mostly due to seasonal nature of this study. Though it would be interesting for further research the use of NDVI interannual variability due to the protracted response from both ENSO, and NDVI response to ENSO, (Mennis, 2001). Similar association patterns between NDVI and SOIa had been been proved by other authors. At looking to table on 13 and 14 it is possible see how slightly weak is this association though existing and their variability, suggesting clear that a fine resolution would be more consistent.

Conclusion

Finally it is possible to conclude especially about the importance of the NOAA AVHRR 8km NDVI on this study despite the slightly weak associations that were found between mangroves and ENSO impacted areas. Such product it is not the first choice to link mangroves greenness to ENSO phenomenon due to its coarse spatial resolution. On the other hand it is important recognize its value due to the higher temporal coverage which allows to assess long-term changes (Maselli, 2004). The use of this product in such a specific type of vegetation (mangroves) as a link to ENSO patterns it is not a common approach among the scientific community. Usually, studies linking ENSO patterns with vegetation vigor are at different land cover level (Anyamba and Eastman, 1996; Anyamba et al., 2002; Lü et al., 2012; Mennis, 2001; Myneni et al., 1996; Nagai et al., 2007).

Other limitation it was the selection of an appropriated threshold to select mangrove pixels. These values had to be adjusted to the cell size of NDVI product (0.0727278) and it was necessary reduce the threshold to almost meaningless values (water ratio- 20%; mangrove ratio -10%) in order to have a total number of 30 pixels.

Such inconvenience is believed to be less by using fine-scale products for datasets, rainfall and NDVI. Future research attempts should increase the number of pixels allowing presenting some more robust conclusions about such an association. Though the use of such fine resolution data would only yield a spatial pattern, not necessarily better robustness as the spatial detail would go at the cost of temporal degrees of freedom.

A very important remark about this study it was the insufficient response of rainfall to explain all the abnormal patterns described above. Such findings alerted for the importance of include on this study other limiting factors such as soil moisture and temperature, for example. Those are known to indirectly and directly, respectively, affect vegetation growth (Wang et al., 2001) and for being requirements for mangroves habitat suitability (Kathiresan and Bingham, 2001a). However, it was not totally unexpected the response from mangrove greenness to rainfall, once it is an aquatic ecosystem and therefore it is not water limited, thus it cannot be disregard the existence of other factors that may be limiting mangrove growth such as temperature and sunlight availability. Temperature was proved to be one of the variables that impacts directly vegetation growth but according with Cao *et al.* (2004) it is negatively associated to primary productivity for tropical regions(Cao et al., 2004). Net primary productivity is the remaining of photosynthetic products that are available for the plant growth or consumption by the heterotrophic community. The decrease of photosynthetic activity on tropical areas reveals the complexity of such association, which was not included given the scope of this study. To conclude, despite the pixels bias the existence of subtle associations between ENSO and mangroves greenness for such high levels of confidence (90% and 95%) is indeed a valuable result taking into consideration the use of NOAA NDVI AVHRR 8km imagery. It is important understand that this study did not focus on the different types of mangroves species that existed on Northern Australia and it merely assess an association; it does not prove causality, so further research would be valuable to untangle the causes and impacts of such an ENSO association on the different types of mangroves across all the Australia.

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Appendix

Annex 1- Mangroves NDVIa vs. Ra Wet Season (90% confidence level 24.d.f.)

Correlation	Mangrove Ratio	Other Vegetation Ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
Non-ENSO					
0.19	10.0	47.0	43.0	92799.6	6851354.6
-0.10	17.0	5.0	78.0	69072.6	11048158.9
0.06	10.0	0.0	90.0	77419.6	6541784.0
0.42	11.0	7.0	82.0	55209.3	7495405.9
0.04	40.0	0.0	60.0	215241.5	25932752.3
0.27	11.0	58.0	31.0	27063.2	7314244.8
0.27	24.0	45.0	31.0	89960.6	15724148.9
ENSO					
0.05	20	59	21	157289.4	12959860.0
0.07	12	50	38	47143.4	8018244.4
0.01	29	50	21	210444.5	18714990.4
-0.27	13	16	71	69639.9	8501908.9
-0.15	15	57	28	141482.6	9682022.0
-0.08	12	38	50	126164.2	7859579.2
0.12	15	34	51	85110.6	9997392.9
-0.18	12	4	84	62425.5	8069084.5
-0.12	27	37	36	119642.8	17821840.8
0.01	17	62	21	58848.4	10911938.5
0.21	13	54	33	84629.0	8419797.6
0.26	13	54	33	99215.8	8883671.3
0.27	12	7	81	104838.1	8253046.6
0.29	23	47	30	119923.9	14913168.8
-0.03	13	20	67	72764.5	8856152.9
0.12	29	17	54	109198.6	18850897.6
0.10	22	24	54	134405.4	14312021.2
0.50	26	36	38	151481.6	17062267.5
0.04	17	34	49	150579.3	10974533.7

0.25	16	18	66	70098.0	10369606.6
-0.04	18	56	26	95495.2	11888942.6
0.18	13	26	61	48394.6	8425550.6
0.15	13	59	28	129372.4	8723435.1
-0.03	18	48	34	98641.0	11557383.0
-0.03	14	9	77	86345.1	9152947.2

Annex 2- Mangroves NDVIa vs. Ra Dry Season (90% confidence level 24.d.f.)

Correlation	Mangrove Ratio	Other vegetation ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
NON ENSO					
0.25	10	47	43	92799.6	6851355
0.17	17	5	78	69072.6	11048159
0	10	0	90	77419.6	6541784
0.22	11	7	82	55209.3	7495406
0.22	40	0	60	215241.5	25932752
ENSO					
0.34	20	59	21	157289.4	12959860
0.46	12	50	38	47143.4	8018244
0.01	29	50	21	210444.5	18714990
0.26	13	16	71	69639.9	8501909
0.14	15	57	28	141482.6	9682022
0.09	12	38	50	126164.2	7859579
0.26	15	34	51	85110.6	9997393
-0.14	12	4	84	62425.5	8069085
0.07	27	37	36	119642.8	17821841
0.25	17	62	21	58848.4	10911939
-0.01	13	54	33	84629	8419798

0.06	13	54	33	99215.8	8883671
0.05	12	7	81	104838.1	8253047
0.02	23	47	30	119923.9	14913169
0.09	13	20	67	72764.5	8856153
0.27	29	17	54	109198.6	18850898
-0.05	22	24	54	134405.4	14312021
0.06	26	36	38	151481.6	17062268
-0.04	17	34	49	150579.3	10974534
-0.24	16	18	66	70098	10369607
-0.11	18	56	26	95495.2	11888943
-0.19	13	26	61	48394.6	8425551
-0.07	13	59	28	129372.4	8723435
0.12	18	48	34	98641	11557383
-0.18	14	9	77	86345.1	9152947

Annex 3- Mangrove NDVIa values for ENSO and NON- ENSO

NON ENSO					
NDVI	**Water Ratio**	**Mangrove Ratio**	**Mangrove Length (m)**	**Mangrove Area (m ^2)**	**Catchment Area (m^2 m^-1)**
0.32	30.0	12.0	135609.8	7965104.0	1721115.4
0.18	77.0	17.0	75980.5	11322070.1	2581673.0
0.17	30.0	20.0	110087.2	12941379.7	3442230.4
0.38	85.0	11.0	49575.6	7201312.2	860557.6
0.24	60.0	40.0	217999.9	26618039.9	860557.7
0.61	29.0	25.0	95785.9	16378406.5	1721115.3
ENSO					
0.34	37	14	75701.9	9275807.8	1776297.1
0.56	80	13	69848.6	8577955.8	3406182.1
0.35	32	15	146067.9	10177697.1	4639751.1
0.55	54	11	119161.6	7603662.3	14300409.2
0.35	58	13	69901.5	8676837.9	2397603.2
0.12	88	11	70067.1	7537520.7	2321355.1
0.61	61	13	46604.0	8321123.6	38275192.5
-0.02	63	18	86195.5	12002313.9	589201.7
0.55	39	25	103236.2	16125638.4	1724823.6
0.57	27	16	54590.8	10588817.2	589212.0
0.57	49	34	143645.3	22163756.6	9844866.1
0.56	35	11	76191.6	7499225.0	1161672.4
0.56	35	14	101766.4	9540831.7	2397612.2
0.60	70	13	103637.9	8581911.2	589211.9
0.56	35	22	121090.7	14590688.0	589212.0
0.58	69	12	64184.3	7822829.4	2321360.2
0.54	57	26	98313.3	17168467.8	1776297.1
0.44	42	25	147319.4	16554560.8	1175095.1
0.02	46	18	161316.1	12123765.2	1161672.5
0.00	65	15	68548.4	10227416.3	375282271.8
0.62	32	17	88861.2	11065510.0	712650154.3
0.28	81	11	107283.5	7538465.5	9347848.8
0.49	33	12	114728.4	7830383.5	1161672.5

0.36	30	12	75869.2	7922645.0	32201782.4
0.17	71	19	107671.9	12166262.6	8094388.0

Annex 4- SOI and NDVIa mangroves correlation for a 90% confidence of level on Autumn Season

Correlation	Mangrove Ratio	Other vegetation Ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
NON ENSO					
0.6	10	47	43	92799.6	6851355
1	17	5	78	69072.6	11048159
-0.2	10	0	90	77419.6	6541784
0.9	11	7	82	55209.3	7495406
-0.1	40	0	60	215241.5	25932752
ENSO					
0.03	20	59	21	157289.4	12959860
0.02	12	50	38	47143.4	8018244
-0.09	29	50	21	210444.5	18714990
-0.5	13	16	71	69639.9	8501909
-0.49	15	57	28	141482.6	9682022
-0.54	12	38	50	126164.2	7859579
0.46	12	4	84	62425.5	8069085
-0.09	27	37	36	119642.8	17821841
0.06	17	62	21	58848.4	10911939
0.55	13	54	33	84629	8419798
0.23	13	54	33	99215.8	8883671
0.17	12	7	81	104838.1	8253047
-0.22	23	47	30	119923.9	14913169
-0.23	13	20	67	72764.5	8856153
0.03	29	17	54	109198.6	18850898
-0.07	22	24	54	134405.4	14312021
0.77	26	36	38	151481.6	17062268
0.89	17	34	49	150579.3	10974534

-0.3	16	18	66	70098	10369607
0.4	18	56	26	95495.2	11888943
0.12	13	26	61	48394.6	8425551
-0.1	13	59	28	129372.4	8723435
0.18	18	48	34	98641	11557383
0.02	14	9	77	86345.1	9152947

Annex 5- SOI and NDVIa mangroves correlation for a 90% confidence of level on Spring Season

Correlation	Mangrove Ratio	Other vegetation ratio	Water Ratio	Mangroves Length (m)	Mangroves Area (m^2)
NON ENSO					
-0.8	10	47	43	92799.6	6851355
-0.1	17	5	78	69072.6	11048159
0	10	0	90	77419.6	6541784
-1	11	7	82	55209.3	7495406
-0.4	40	0	60	215241.5	25932752
ENSO					
-1.1	20	59	21	157289.4	12959860
-1.5	12	50	38	47143.4	8018244
0.4	29	50	21	210444.5	18714990
-0.6	13	16	71	69639.9	8501909
0.2	15	57	28	141482.6	9682022
0	12	38	50	126164.2	7859579
-0.4	12	4	84	62425.5	8069085
0	27	37	36	119642.8	17821841
0.3	17	62	21	58848.4	10911939
0.1	13	54	33	84629	8419798
0.5	13	54	33	99215.8	8883671
-0.3	12	7	81	104838.1	8253047
0	23	47	30	119923.9	14913169
0.4	13	20	67	72764.5	8856153

-0.1	29	17	54	109198.6	18850898
0.1	22	24	54	134405.4	14312021
0.1	26	36	38	151481.6	17062268
0.1	17	34	49	150579.3	10974534
1.5	16	18	66	70098	10369607
1.3	18	56	26	95495.2	11888943
0.5	13	26	61	48394.6	8425551
0.6	13	59	28	129372.4	8723435
-0.5	18	48	34	98641	11557383
0.1	14	9	77	86345.1	9152947